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Cutter Energy Efficient Lighting

Cost Study Report

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Rich Hansen
Surface Branch Chief
United States Coast Guard
Research & Development Center
1 Chelsea Street
New London, CT 06320

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The R&D Center's technical point of contact is Thomas L. Amerson, 860-271-2894, email: Thomas.L.Amerson@uscg.mil

16. Abstract (MAXIMUM 200 WORDS)

Results of a study evaluating potential energy/cost savings by transitioning to more efficient lighting technologies on U.S. Coast Guard Cutters.

Three approaches were used: (1) a review of U.S. Navy ship lighting transition from fluorescent lights to light emitting diodes (LED), (2) lighting surveys on two Coast Guard Cutters, and (3) a Coast Guard LED cost model. The cost model was developed to compare fluorescent lighting with up to four alternative lighting technologies. Cost calculations included factors like upfront investment, component replacement, power consumption, technology-specific configuration, disposal, labor, annual light usage, and cost of electrical power.

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EXECUTIVE SUMMARY

In support of Executive Order 13514 and Department of Homeland Security efficiency initiatives, the Coast Guard has a goal for its facilities and cutters to reduce greenhouse gases, energy consumption and expenses. One method being considered is retrofitting existing interior shipboard fluorescent lighting fixtures with energy efficient Light Emitting Diode (LED) technology. This study was commissioned to evaluate this potential energy savings concept using three approaches. The first approach was to review the U.S. Navy's transition from fluorescent shipboard lighting to LED lighting. The second approach was to conduct lighting surveys on two U.S. Coast Guard Cutters, one having legacy fluorescent lighting and the other having experimentally transitioned to LED lighting. The third approach was to construct a detailed cost model tailored to U.S. Coast Guard Cutters and operations to provide estimations of energy savings, consequent operational cost savings, and technology payback period with a transition to LED lighting. Throughout the effort, recognition was given that Cutter lighting is associated with human factors and that the selection of an energy saving light technology must continue to support the human systems user with appropriate lighting intensity, color rendering, and overall appearance.

The U.S. Navy determined in 2001 that legacy lighting was expensive and accounted for a significant portion of the ship's fuel consumption. Thus, the U.S. Navy has made its decision to pursue transition to LED lighting based upon the rising burdened cost of fuel and trending data showing that LED lighting is becoming less expensive. The Office of Naval Research funded LED development projects, and the Naval Postgraduate School developed business cases demonstrating the value of transitioning to LED lighting on Navy ships. A large refitting project was begun in 2009 to convert many Navy vessels to LED lighting by 2014. In addition to fuel cost savings, an important factor in the USN decision to transition to LED lighting is the resulting reduction in carbon emissions, a move to "green" operations.

The CG study team conducted two lighting surveys. A lighting survey conducted on the CGC IDA LEWIS (WLM 551) measured illuminance from legacy fluorescent lighting. A lighting survey conducted on the CGC MACKINAW (WLBB 30) measured illuminance from COTS LED lighting in corresponding ship's spaces. Although the power consumption of LED lights is about one-half that of the fluorescent lights, the illuminance values were generally much higher for the LED lights. The LED lighting provided even, bright illumination without harshness or tinting. Improvement in color balance was explained by the increased broadband spectrum of the LED light compared with the narrow band spikes of the fluorescent light. The study team concluded that the LED lighting quality was comparable, if not better, than fluorescent lighting.

A cost model was created in Microsoft Excel comparing the life cycle costs of alternative lighting technologies with the life cycle costs of the baseline lighting technology, fluorescent lighting. Calculations included upfront investment costs, component replacement costs, and power consumption costs. Configurations of the alternative lighting technologies included the fixture, lighting bulbs/strips, backup power devices, a driver card, and peripheral material such as wiring. The model included factors that were specific to a lighting technology such as the type of light, fixture cost, life expectancy of the specific bulb, power consumption of the type of light, and disposal costs. Other factors were associated with all the lighting technologies and included factors such as labor cost, annual light usage, and cost of electrical power in the same operating area.

The cost model yielded key performance results such as upfront/initial investment cost, payback period for the alternative lighting technology, estimated total savings, and the Net Present Value of the savings spread over the years of vessel use. A sensitivity analysis of the cost model was conducted for a notional WMEC class vessel with its homeport in Key West, Florida. Cost model factors such as price of electricity, life of vessel, light usage, labor rate/hours to install LED lights, LED life expectancy, and power consumption of lighting fixture were each varied by incremental changes of 10% over a range going 50% either side of nominal. The factor sensitivity analyses determined how much the payback period, estimated total savings, NPV of the estimated total savings, percentage savings in labor hours, and percentage in annual power consumption reduction would be affected by variations in these factors.

Key results of the WMEC 270 class analyses included (30 years of vessel life assumed):

- The estimated payback period for MILSPEC LED installation was approximately 8.5 years.
- Though the MILSPEC LED installation is more expensive than commercial off the shelf type LEDs, a 30 year cumulative savings of approximately $400,000 per vessel was seen even with 50% increases in expense factors.
- The most significant effect on estimated total savings determined by the factor sensitivity analyses were *Bulb Power (Energy) Consumption*, *Number of Fixtures*, and *Cost of Power At-Sea*
- A 30% decrease in *Fixture Purchase Cost* lowers the payback period to 6 years. A 30% decrease in *Bulb Power Consumption* lowers the payback period to 7 years. Inversely, a 30% increase in *Fixture Purchase Cost* or *Bulb Power Consumption*, the payback period rises to approximately 10.5 years.

Based upon researching the USN transition to LED lighting, the lighting surveys conducted on CG Cutters, and the results of the cost model runs, the following recommendations can be made:

- LED lighting should be installed on all new construction Cutters.
- Any cutter having more than 10 years of service life projected should be considered for re-fitting to MILSPEC approved LED lighting. MILSPEC lighting will not produce the savings of commercial off the shelf LED lighting; however, the additional testing and measures taken to reduce unwanted electrical noise (dirty power) on the ship's circuits makes this lighting option preferred until commercial lighting becomes more standardized.
- The return on investment will be greater in the areas having high electricity prices. Testing or implementing LED lighting transition should be applied to such areas first.
- A good candidate for a test platform is the 140 WTGB because the planned SLEP for this platform is imminent and a current line item for project execution is LED lighting.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABS	American Bureau of Shipping
AC	Alternating Current
CCT	Correlated Color Temperature
CEC	Canadian Electrical Code
CG	Coast Guard
CGC	Coast Guard Cutter
CGTO	Coast Guard Technical Order
COMDTINST	Commandant Instruction
COTS	Commercial Off The Shelf
CRI	Color Rendering Index
DARPA	Defense Advanced Research Projects Agency
DE	Data Entry
Deg K	Degree Kelvin
DoD	Department of Defense
ECC	Canadian Electrical Code
FRR&DP	Fleet Readiness Research and Development Program
HAZMAT	Hazardous Material
Hz	Hertz
i	Discount Rate for Net Profit Value
ID	Identity
IES	Illuminating Engineering Society
K	Kelvin
k	Kilo
kWh	KiloWatthours
LED	Light Emitting Diode
LLC	Limited Liability Company
LX	Lux
MIL-DTL	Military Detail Specification
MILSPEC	Military Specifications
MIL-STD	Military Standards
N	No
NAVSEA	Naval Sea Systems Command
NEC	National Electrical Code
NPS	Naval Postgraduate School
NPV	Net Present Value
NSTM	Naval Ships Technical Manual
NSWCCD-SSES	Naval Surface Warfare Center Carderock Division

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

ONR	Office of Naval Research
R	Net Cash Flow in Net Present Value
RDC	Research and Development Center
ROM	Rough Order of Magnitude
SC	Support Calculations
SFLC	Surface Forces Logistics Center
SLEP	Service Life Extension Plan
SPD	Spectral Power Distribution
SSL	Solid State Lighting
TCO	Total Cost of Ownership
U.S.	United States
USN	United States Navy
V	Volt
VAC	Volts Alternating Current
VDC	Volts Direct Current
W	Watt
WLBB	Icebreaker
WLM	Coastal Buoy Tender
WTGB	Icebreaking Tug
Y	Yes

1 BACKGROUND

In support of Executive Order 13514 and Department of Homeland Security efficiency initiatives, Coast Guard facilities management and cutter crews have recommended reducing energy consumption and expenses by retrofitting existing interior fluorescent lighting fixtures with energy efficient Light Emitting Diode (LED) technology. In recent years, LED lighting technology has matured rapidly, enabling mainstream applications that promise long-term life, vibration resiliency, significant energy savings, and reduced hazardous materials (HAZMAT) disposal when compared to legacy lighting technologies. The vast majority of Coast Guard energy efficiency efforts have focused on shore side installations. However, this narrow focus on shore-side facilities should be expanded to acknowledge that a cutter moored to a Coast Guard pier draws more power from the same energy grid than a comparable shore side facility. Most large cutters are drawing power from a shore-side energy grid for at least 180 days per year (Enclosure (2) COMDTINST 3100.5B), with patrol boats typically requiring shore side energy for up to 273 days per year. In most cases, these cutters are outfitted with older style electrical gear and lighting, resulting in a significant energy demand from the shore-side grid.

Although LED lighting technology costs per unit are higher than traditional fluorescent or incandescent units, LED lifespan is reported to be, at minimum, 3-5 times longer than the fluorescent units. Additional savings with LED lighting are realized in reduced time spent in personnel changing the lamps, costs associated with fluorescent lighting ballasts that often require replacing (and can be a fire hazard), and the HAZMAT disposal required for fluorescent bulbs that contain mercury.

The U.S. Coast Guard Research and Development Center (RDC) initiated a cost model study of the potential use of LED lighting on CG cutters. The development of the CG cost model began with a review of USN evaluations of such lighting for use on their ships. In conducting this review, several LED manufacturers were contacted to obtain updates to their technologies and current price schedules. RDC used its photometric laboratory expertise and equipment for lighting surveys on cutters having either fluorescent or LED lighting. These surveys provided first hand spectral characteristics of the lights, data on efforts required for LED fixture conversion, and direct experience with the visual experience of LED lighting on cutters. Though the primary effort driving the report was the cost model, these additional efforts were taken to validate the feasibility of LED retro-fitting and to acquire data, not otherwise available, to feed the cost model.

1.1 Review of U.S. Navy Lighting

There has been no lack of attention by the USN towards the potential and benefits of using LED lighting instead of legacy fluorescent lighting on USN ships. Even a cursory effort to identify USN generated evaluations finds considerable study in academe (Naval Postgraduate School), in the research community (the Office of Naval Research), in program offices at Naval Surface Warfare Center, Carderock Division-Ship Systems Engineering Station (NSWCCD-SSES), and among commercial product providers to the USN.

At the request of the Director of Innovation at the Office of Naval Research (ONR), the Naval Postgraduate School (NPS) directed work to examine the USN's implementation of innovation (Freymiller, 2009). Cizek (2009) directed his master's these towards a business case analysis comparing the life cycle costs of LEDs with current fluorescent overhead lighting. His findings were that cost savings to the USN would result from reduced energy demand and reduced maintenance requirements for LED lighting.

Cizek's thesis (2009) cites several key studies considering LED lighting for USN ships. As early as 1997, LED lighting was reviewed by the Navy's Affordability Through Commonality project; however, it was dismissed because the designs at the time did not produce acceptable levels for shipboard illumination (Gauthier & Green, 1997). Another analysis (Lovins, 2001) observed that the energy waste found on USN ships accounted for approximately one-third of the ship's fuel consumption. They claimed that lighting was a significant contributor to this waste. Further studies cited by Cizek (2009) viewed the reduction of electrical energy waste as important in providing a greater energy reserve that could be applied to new combat systems and reduce overall operating expenses as fuel costs continue to increase (DoD, 2008). With the development of Military Specifications in solid state lighting design and use (NAVSEA, 2008), the way was made for standardization and an accelerated implementation of LED lighting on USN ships.

The guiding premises of Cizek's work (2009) were that the USN needs to reduce its total cost of ownership (TCO) of its fleet platforms and that newer technologies, such as LED lighting, could provide important savings to the USN as it attempts to move towards more economical ship design. His research questions centered around (a) the costs and benefits of LED lighting installation on USN ships and (b) the organizational impediments to implementing LED lighting.

Cizek (2009) claimed that newer LED lighting technology is "the most energy-efficient light source available" using "85% less energy" and lasting "thirty times longer than incandescent bulbs" (p. 4). When compared with compact fluorescent lighting, "LEDs use half as much energy and last almost five times longer." Given these savings, the ideal customers for LED lighting are those who need constant, 24 hour illumination and have to include the maintenance costs bulb replacement in their budgets. Citing the current high costs of LED technologies, Cizek claims that LED prices are dropping due to increasing sales and that current prices "are decreasing by 25% per year" (p. 5). He cited claims by the Department of Energy that, in 20 years, LEDs will comprise "70% of the general lighting market" (p. 5).

In a comparison of incandescent, fluorescent, and LED lighting on several performance variables, Cizek (2009) offered the following observations (p. 7):

Table 1. Comparison of current lighting technology.

Performance Variable	Incandescent	Fluorescent	LED
Color Rendering Index	100	62-82	92
Color Temperature (degrees Kelvin)	2700-3300K	4100K	2500-6000K
Efficacy (lumen/Watt)	12-15	50-100	60
Lifespan (hours)	1,000	10,000-20,000	50,000

The Color Rendering Index (CRI) is a measure of the trueness or accuracy of color appearance under the light. Sunlight and incandescent light are indexed at 100. From Table 1, it can be seen that LED lighting provides a higher CRI than fluorescent lighting, even approaching that of incandescent lighting. Fluorescent lighting has a significantly lower CRI and has long held a reputation for distorting the appearance of colors. Color distortion can be an important issue in workplaces where color-coded displays are used. The appearance of lighting has been related to the Correlated Color Temperature (CCT). Lower CCT lighting is often associated with "redder" or "warmer" whites; lighting with higher CCT values, such as seen in fluorescent lighting, is frequently described as being "bluer" or "cooler." These appearances have been mitigated somewhat through the use of phosphor coatings on the lighting tubes. (It should be noted that LED lighting comes in a wide range of CCT and that manufacturers trying to achieve Military

Specifications to match fluorescent lighting have matched the LEDs at 4100K.) Efficacy values reported by Cizek (2009) continue to improve for LED lighting with current values reported at 60. Efficacy values can be related to the relative waste of input energy as outputted heat. This heat has to be managed for safety, to prolong the operating life of the luminary, and to maintain comfort levels for persons in the lighted spaces. The reported lifespan of LED lighting is much greater than that for fluorescent lighting and, with continued technology improvements, is approaching 80,000 – 100,000 hours. This factor greatly reduces the maintenance cost associated with changing failed bulbs.

Freymiller (2009) commented on the non-technical challenges to transitioning to LED lighting aboard USN ships. With an already limited commercial market for LEDs, he observed that the requirement to meet military specifications would drive the costs beyond market acceptability. He commented on three approaches to reducing the costs of LED transition (or any technology transition). The first approach is to wait until the technology is more mature, has a larger buying public, and shows a corresponding drop in cost. Unfortunately, the USN requirement for LEDs to meet military specifications works against the "waiting" approach. The market share of the military version of the LED will likely remain a niche product and costs will tend to remain significantly higher than those of the general market. The second approach to reducing the cost of technology is to buy in bulk. Although bulk purchases typically provide the greatest savings in unit price, Freymiller posits that the volume of USN purchases of LED lighting for its ships might not be sufficient to drive the costs down significantly. He also cited Fiscal Law and the bona fide needs statute that limit the purchase of items in U.S. Government excepting for contracts properly made in the period. This argument, however, seemed weakly supported in his thesis. The third approach to reducing costs that Freymiller offered is to promote competition by having LED manufacturers compete to produce the most cost effective LED technology and then awarding the winner with a large contract to convert the fleet over to LED lighting. This approach has been successfully used with other technologies by many agencies.

It appears that, from the USN perspective, the clear advantage of LED over fluorescent lighting rapidly moved beyond academic considerations. By the time Cizek and Freymiller completed their theses, Naval Sea Systems Command had already committed to LED shipboard installations to be conducted over the 2010-2014 timeframe. The Naval Sea Systems Command (T. Garland, personal communication, November 22, 2008) published its approval notice of a supplement for military specifications for solid state lighting (MIL-DTL-16377). This notice specified "Naval shipboard lighting fixtures and associated parts for both new construction and in-service Fleet." Citing the "reliability, durability, and cost efficient advantages" of solid state lighting, this notice invited vendors who could meet the requirements to submit their test results to the Naval Surface Warfare Center Carderock Division (NSWCCD) for an "approval for use" issuance upon demonstrating that the requirements were met. This notice and the list of vendors to which it was sent is included in Appendix A. Several vendors have produced innovative LED systems to make their products beneficial to the USN.

Getting to the position that LEDs could be considered for replacing legacy bulbs has required some investment by the USN. ONR and the Defense Advanced Research Projects Agency (DARPA) have supported industry research to develop energy efficient LED fixtures to replace fluorescent bulbs on Navy ships and submarines. One such company, Energy Focus, Inc., developed lighting that was qualified to retrofit lighting on two USN destroyers (Energy Focus, 2011). Several lighting styles were produced including the T-5 fluorescent fixtures found in berthing areas. The company claimed the 80% savings with the LEDs would significantly benefit the USN that spends $.55 per kilowatt hour for electrical energy. The company claimed that the resistance of the lights to vibration would add important benefits over either incandescent or fluorescent bulbs.

Another company that has invested in meeting the Navy's requirements is 3M. They claim their efforts have produced an LED that exhibits twice the efficiency of fluorescent bulbs, has a smaller form factor, and has an 80,000 hour lifespan with a 500,000 hour mean time between failures for the LED power supply. The savings in weight for their fixture can be 5 tons for 1573 fixtures over legacy fluorescent fixtures (3M Defense, 2011).

Energy Focus, Inc. (2011) conducted LED lighting studies under contract to ONR and DARPA. Its products are designed to replace T-5 and incandescent globe fixtures with LEDs at a savings of at least 80% of the energy. One important bulb quality that Energy Focus concentrated on in their studies was to make the LED bulb vibration resistant. The successes of their studies have led to U.S. Navy orders for ship relighting.

Improved LED efficiency has led to increased projected energy savings. In a Fleet Readiness Research and Development Program (FRR&DP) project, the USN refitted approximately 4,000 LED fixtures and calculated annual fuel savings of 857 barrels per ship for Arleigh Burke Class destroyers and annual savings of 335 barrels per ship for Wasp Class dock landing ships (A. Vigliotti, personal communication, October 19, 2011).

Oxley, Inc. (Towman, J, personal communication, January 11, 2012) has produced the EFL series of commercial lighting that they have been preparing for meeting military standards. This series was designed to be powered by 110 VAC, 230 VAC, or 20-32 VDC using a self-contained universal driver. This product also features several novel local and external dimming features. It claims an operating temperature range of -40 to 158 deg F exceeding the lower temperature requirements cited in MIL-DTL-16377. With a color temperature range of 4500-6000 deg K, a CRI greater than 70, and a LED efficacy >112 lumen/W, the manufacturer reports this light as comparing favorably with fluorescents.

The L.C. Doane Company, with a lengthy history of providing military standard fluorescent lighting fixtures and tubes, has developed a line of USN Military Specification LED lighting that is certified to meet the MIL-DTL-16377/8 standards. This vendor has sold units to the USN for the transition to solid state lighting.

In summary, the USN supported LED technology studies and development through targeted ONR and DARPA projects, studied the energy savings and reduced fuel costs resulting from transitioning away from incandescent and fluorescent lighting to LED lighting, demonstrated these energy benefits in a FRR&DP project, and continues to develop procurement and installation strategies for implementation with existing and future vessels (Kristiansen, 2010).

2 U.S. COAST GUARD CUTTER POWER AND LIGHTING

The RDC conducted a review of current lighting status and requirements for CG Cutters. The USCG specifies lighting to meet one of three standards: Naval Ships Technical Manual NSTM standard 330, Illuminating Engineering Society IES standards for lighting or American Bureau of Shipping (ABS) Guide for Crew Habitability on Ships. The use of these references for lighting is due to the different construction times and builders of vessels in operational use in the CG.

Lighting installed in CG Cutters typically consists of 2ft and 4ft linear fluorescent bulb fixtures taking several configurations and incandescent globe lights. This RDC report primarily considered the impact of LED bulb technology replacement for linear fluorescent bulbs due to the large quantity of these lighting fixtures in the fleet.

2.1 Cutter Electrical Power Systems and Consumption

Electrical power for Coast Guard Cutters is either generated onboard or is obtained by connecting to shore-based facilities when the Cutter is in port. Onboard generation is achieved through an amalgamation of diesel engine driven equipment. Main shipboard power generation is at 450-480 Volts AC at 60 Hz. Voltage is stepped down to 120V and further distributed to various circuits through the cutter. Cutter electrical systems are required to meet the power standard MIL-STD-1399 section 300. This standard is followed to ensure safe operation of all electrical equipment on-board and to reduce integration issues with all other Cutter installed electrical equipment. Commercially generated power is delivered through a shore connection ship's bus to be stepped down and distributed through the ship's systems.

Electrical power cost for shipboard electrical generation is dependent upon efficiency and overhead cost associated. Fuel costs, engine size, and labor associated with maintaining engines and electrical distribution factor into the cost of onboard electrical power generation. Energy audits of Coast Guard Cutters in 2011 determined a general price of $0.42 per KWH as a baseline (Alaris Companies, LLC, 2011). Cost of shore power varies greatly from region-to-region and can range from $0.08 to $0.45 plus local peak demand charges. Charges change based upon historical usage to program demand charges and demand ratchet charges (Capehart, B., Turner, C., & Kennedy, W., 2008). When receiving shore power, Cutters are moored to a large facility such as a Base Support Unit (BSU) or Sector, and all energy consumed is typically bundled to one meter. Comparisons of regional power costs are available online (Eisenbach Consulting, LLC., (2011). Electricity Prices by State – National Electric Rate Information. Accessed January 11, 2012, from http://www.electricchoice.com/electricity-prices-by-state.php).

The use of onboard electrical power generation or commercially supplied electrical power is largely a function of whether the Cutter is underway or at port. Cutter schedules are based upon availability of resources and missions. Vessels are underway approximately 185 days per year thus leaving 180 days in-port typically connected to a commercial power source (Enclosure (2) COMDTINST 3100.5B). In many cases, however, the Cutter will use its diesel generators to produce its own power even when at port. These circumstances usually result when the facility does not have the capacity to deliver the amount of power needed by the Cutter or when there is no formal agreement available to purchase the power.

Electrical power is consumed by a variety of components on the Cutter. Sensor systems, information technologies, air conditioning and heating, galley appliances, and lighting are heavy consumers of electrical power. Additionally, electrical power is needed for propulsion systems (e.g., propulsion exciters, salt water pumps, lube oil pumps, and bilge systems). Crew members consume electrical power through the use of devices such as flat screen televisions, personal computers, music players, shavers, and hair dryers. However, a significant amount of electrical power aboard the Cutter expended in energizing ship's lights. Lighting is typically left on inside compartments of the ship 24 hours per day during in-port. While cutters are underway lighting is dimmed to night lighting from sunset to sunrise based on the location of the Cutter. Electrical lighting load is on average 7-14% of the Cutter's electrical load (Alaris Companies, LLC, 2011).

All items integrated into the ship's energy system contribute to the ship's overall power demands and quality. Integration of new energy components to the Cutter need to be taken into consideration.

Large cost savings can be obtained by reducing electrical power consumption in-port and while at sea. The U.S. NAVY lighting decision for converting to solid state lighting used underway cost of power generation as the main cost savings measure (NAVSEA SSL presentation 08). Utilizing maintenance, power consumption, replacement parts, and disposal costs, LED lighting return on investment cost over legacy lighting are reduced dramatically. Early indications suggested that installation of energy efficient lighting alternatives could save up to 50% of this load or change the lighting load consumption to 3.5-7%.

2.2 Cutter Lighting Designs

Lighting installed in CG Cutters is primarily 2ft and 4ft linear fluorescents with several configurations and incandescent globe lights. These "legacy lights" are often referred to by their configuration listings. These lighting systems are classified differently by manufacturer, and encompass incandescent and fluorescent fixtures. Shipboard lighting fixtures fit into three different categories: (1) MILSPEC fixtures meet MIL-DTL-16377H. These products are robustly tested to meet rigorous standards for shock, vibration, impact, electrical interference, illumination, and wet/harsh environmental conditions. (2) Marine grade lighting is corrosion resistant and weatherproofed. There is no single definition for marine grade in terms of requirements industry must follow. It is a generalized term and testing to different standards can qualify as marine grade. The following are some different industry standards use to claim marine grade products: Underwriters Laboratory UL1598A-Marine, ABS, Canadian Electrical Code (CEC) and the National Electrical Code (NEC) Type 4X, suitable for outdoor corrosive environments. (3) General lighting refers to any lighting fixture available commercially off the shelf (COTS). As suggested by the categories, these lights differ relative to ruggedness and marine environment use.

Engineering plans for lighting placement are based upon amount of space in a compartment and the designed use of the lighting. Light output from the fixture is then taken into consideration and the height or distance the light will be from the task area. Coast Guard Cutters require several types of lighting to operate during any night and day conditions. All of the linear fluorescent lights on the cutters have T12 bulbs with older magnetic ballasts. Current interior lighting is calculated during the building phase of the Cutter and the number of fixtures is generally related to the length of the vessel. Larger vessels require more interior lights. Unfortunately, many ships' configuration data are lacking. Lighting is listed on some cutter classes as one line item with the quantity of one. Some general examples are 270' WMEC have 1774 Lighting fixtures. The newer 157' FRC has 1592 fixtures installed.

For illustration, lighting calculations for a specific compartment may require three fixtures for the appropriate luminance levels, but due to space configuration, all installed lighting may be found on one side of the compartment to accommodate other furnishings taking precedence. Seawater piping, fire main, pneumatic piping, and cable runs are installed in the overhead with the overhead lighting fixtures installed to one side of the bow thruster space. Such installations may not be faithful to the ship plans. Such physical placement of lighting results in light and dark areas within different areas of the ship.

Included in the Cutter lighting design is the requirement for a replacement parts space for bulb and ballast. Due to the relatively short lifespan of fluorescent lighting and the environment, multiple spare parts need to be carried with the Cutter. Additionally the HAZMAT concerns associated with fluorescent lighting require all ballasts (possible PCB source) and used lamps (mercury vapor source) to be recycled. Larger ships with longer operational periods carry more spares, taking more space. To increase efficiency the use of Cutter spaces, lighting could be replaced at set schedule to negate possible failures but this approach also increases frequency of lamp and ballast change outs and drives up the overall cost of the lighting system.

2.3 Engineering Considerations with Lighting Technologies

System performance varies across lighting alternatives. Table 2 provides comparisons in performance elements that are important to the CG in Cutter operations:

Table 2. Comparison of lighting technologies.

Performance Element	Incandescent	Fluorescent	LED
Life Span (average)	1,200 hours	`8,000 hours	~50,000 hours
Power Consumption	60 Watts	18 - 40 Watts	6 – 22 Watts
HAZMAT Consideration	No	Yes	No
Sensitivity to Low Temperatures	Some	Yes – under negative 10°F	None
Sensitivity to Humidity	Some	Higher failure rate in humid climates	No
Sensitivity to On-Off Cycling	Some	Yes – reduced lifespan	No Effect
Instant On Activation	Yes	No – ramps up to max light output	Yes

Costs associated with current LED lighting designs vary by required specifications. Several manufacturers were contacted and asked for rough order magnitude (ROM) pricing for products. As more suppliers come online having the 4 differences in the cost model are a good way to quantify what system would be suited best for the Coast Guard fiscally. Costs for retrofitting fixtures to replacement COTS systems averaged $40.00-$90.00 per light bulb. Marine specification enclosures are required to retrofit legacy systems. Marine specifications themselves were currently not available but Oxley group lighting is encased in a marine tight fixture and further testing would need to be conducted pricing ranged from $320.00-$460.00 per assembly (Towman, J, personal communication, January 11, 2012). MILSPEC lighting solutions are available in two different options including ballast compatible light bulbs in 2' lengths for $150.00 each from Energy Focus or complete fixtures $288.00-$665.00 from LC Doane.

General considerations regarding Cutter lighting:

- The lifespan of installed Cutter lighting may not be as advertised due to overstated manufacturer claims or to the rigors of the maritime environment.
- Actual energy consumption may be higher than planned due to operational practices.
- Replacement lamps are ordered on Cutters by the installation technicians on smaller assets. Due to the small storage spaces and unknown availability of next opportunity to purchase replacements, shipboard engineers purchase multiple replacements and use them as needed upon failure.
- Due to the commonality of lighting systems and many light bulb types fitting into the standard bases, lamps may be mismatched with the installed ballast and shorten lamp life expectancy to as little as a couple of weeks.
- Fixtures are normally designed with complete system engineering processes including heat management; installation of incorrect bulbs may reduce the performance and efficiency of the system.

- LED lighting meeting the supplemental MILSPEC meets or exceeds all objective and threshold values. Energy Focus, LC Doane, and Light – Pod have approved interior shipboard products.
- At a minimum the original lighting requirements for the cutter should be used as a baseline for requiring SSL (Solid State Lighting) or LED (Light Emitting Diode) lighting. Also, the new fixtures should meet or exceed the lighting calculations, study or survey thresholds for the cutter class in the original documentation.

Engineering concerns specific to LED lighting on Cutters include:

- Underloading shipboard power generation. Underloading a diesel engine can cause internal mechanical damage. There is a concern that the operation of LED lighting can reduce the lighting load of a ship up to 50% and create underloading of the diesel engine. However, most legacy Cutters experience increasing demands for shipboard power generation (beyond the initial design expectations) due the integration of new electronic equipment over their lifespan. Lighting load measured by Alaris energy audits onboard three different Cutter classes showed the lighting power consumption to reach up to 18% of the ship's designed electrical load. Reducing the Cutter's power consumption would ease the burden of many already overloaded legacy systems. Newer Cutters can take the design factors of more power efficient lighting into consideration prior to production. Benefit to existing Cutters could be to reduce loads to the point that a single generator could be used in some in-port situations when power cannot be supplied by the facilities.
- Dirty power generation. Another concern for consideration is the possible side effect of installing multiple LED Direct Current (DC) driven devices which can introduce electrical noise into the ship's power grid and diminish the power quality of the entire Cutter. Whether this happens from the installation of COTS LED systems needs to be tested. MILSPEC qualified lighting has already passed rigorous testing and addresses this concern. MILSPEC LED lighting meets MIL-STD-1399 section 300, the standard for power interface requirements.
- COTS lighting product claims. Of particular concern are lifespan claims, luminous intensity, and heat management. MILSPEC and marine grade lighting offer some assurances of manufacturing claims.

3 U.S. COAST GUARD CUTTER LIGHTING SURVEYS

3.1 Photometric/spectral Characteristics of Fluorescents and LED Lights

The measurement of light requires some familiarity with terminology and measurement units. The following paragraph provides a basic discussion of terminology important in the understanding of the lighting surveys conducted on CG cutters.

Illuminance refers to the luminous flux per unit area that arrives at a particular place on a surface from one or more sources of light. Figure 1, is a schematic representation of light distribution in a room that shows how light originating from multiple sources can illuminate a surface. When conducting lighting surveys to determine adequacy of lighting in an area, it is illuminance that is being measured. The unit for illuminance is the lux (lx).

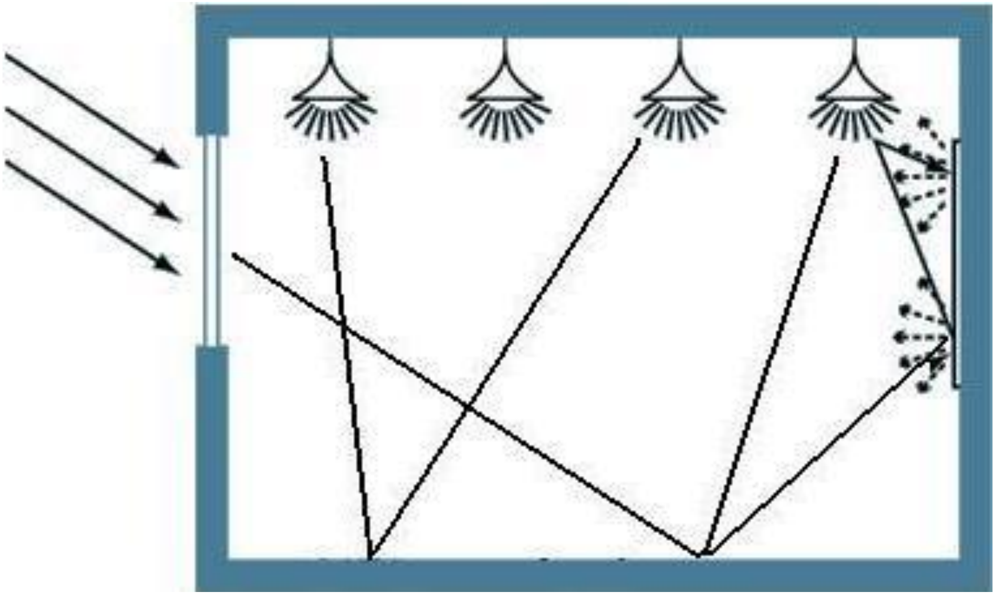

Figure 1. Light from multiple sources arriving at various surfaces in a room.

In addition to the amount of light available to the observer, lighting surveys also include measures of the spectral components of the light. Spectral Power Distribution (SPD) refers to the amount of light measured at each wavelength across the entire visible spectrum. Figure 2 presents the in SPD for three types of light sources: incandescent, LED, and fluorescent lighting. The incandescent light exhibits a classic black body radiator SPD. It produces light power at all wavelengths across the entire visible spectrum (broad band) and on into the infrared (heat). This light has historically been considered the most pleasing and providing the best color rendering. However, incandescent light produces much non-visible infrared and is, therefore, energy inefficient. Conversely, the LED shown in Figure 2 produces light only in the visible part of the spectrum and is thus much more efficient. The fluorescent light shown in Figure 2 produces light in the visible part of the spectrum; however, it also produces a small amount of ultraviolet light can be destructive to plastics and has been found to be biologically injurious. Fluorescent lighting is not as efficient as LED lighting in converting electricity to light. Fluorescent lights produce light at discrete wavelengths (called spectral lines) in contrast with the broadband character of incandescent light. Fluorescent lights are designed to produce a particular “type” of light i.e. soft white, cool white etc. by adjusting the size and location (Figure 2) of the spectral lines. Unlike a fluorescent light, the LED produces light across the entire visible spectrum and therefore has a character that more closely resembles incandescent light. As noted earlier in the report LEDs have CRIs between 80 and 92 whereas typical fluorescent tubes found in commercial lighting have a CRI of between 55 (warm white) and 62 (cool white).

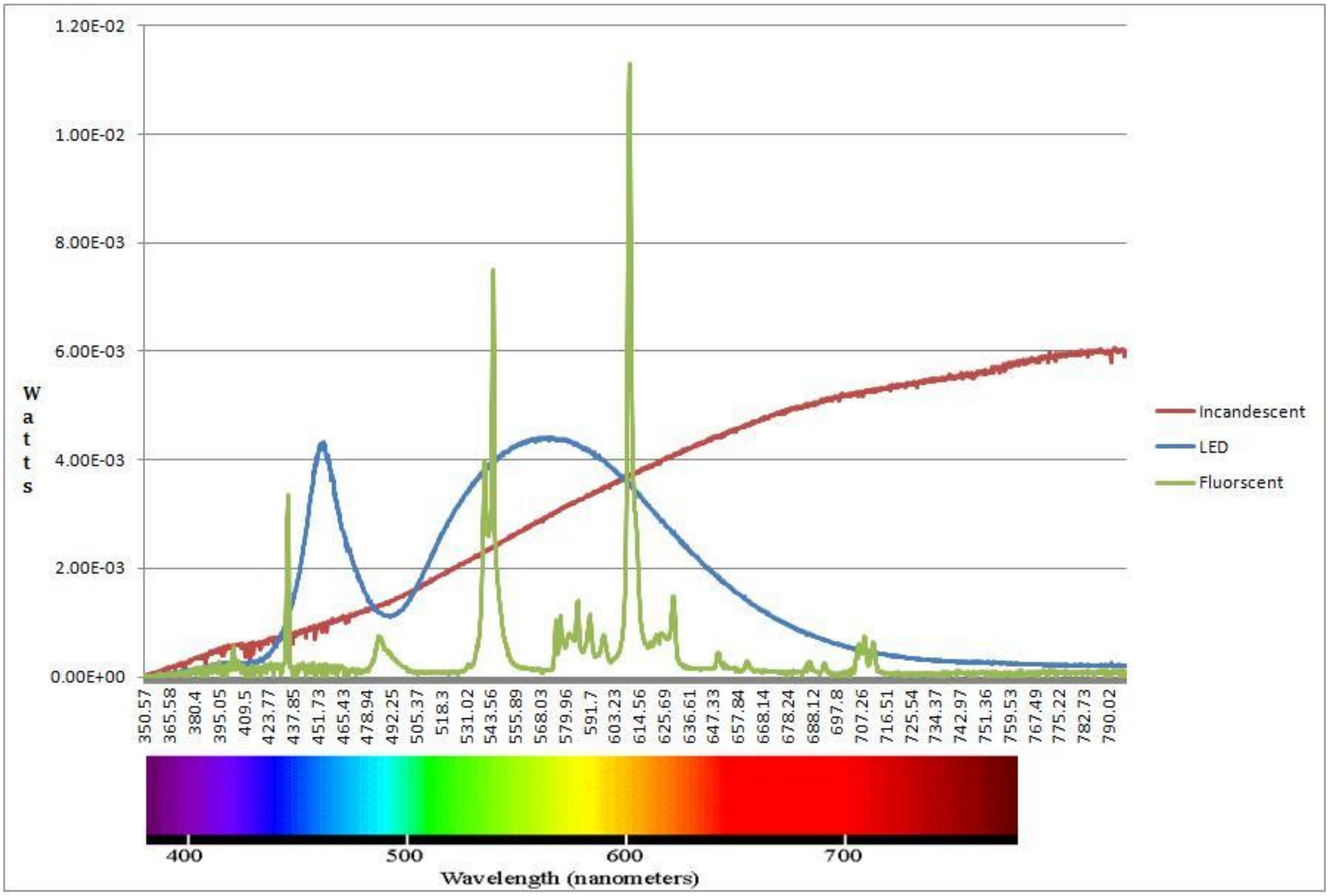

Figure 2. A comparison of the spectral power distribution of incandescent, fluorescent and LED light sources.

3.2 Output of LED Lighting Compared with Fluorescents

Correlated Color Temperature does not tell the whole story when selecting a light source. The CCT designation for a light source gives a good indication of the lamp's general appearance, but does not give information on its specific spectral power distribution. (RPI Lighting Research Center Accessed May 2, 2012 from http://www.lrc.rpi.edu/education/learning/ terminology/cct.asp-) The CCT of fluorescent lamps is achieved by combining wavelengths of light in different amounts so that it produces light that appears white to the eye. It is possible that the light from two lamps can have different wavelength combinations and yet appear exactly the same color (same nominal correlated color temperature), but their effects on objects may be very different.

The CRI is a measure of how natural objects will appear when illuminated by a light source. The spectral make-up of a light source affects its ability to render colors "naturally”. Figures 3 and 4 (from Lighting Research Center Resource Collection) contrast the color rendition of a fluorescent light with an LED. Although both have a color temperature of about 4100 degK, they have different spectral power distributions. This can be seen in Figure 2, the LED has a more evenly distributed SPD and therefore also has a better CRI. Typically a cool white fluorescent bulb has a CRI of about 62, whereas an LED has a CRI above 90.

When evaluating different types of lighting, it is important to take into consideration not only the CCT but also the CRI when trying to produce a more natural lighting environment. The members of the crew on CGC MACKINAW commented that things looked better with the new LED lights.

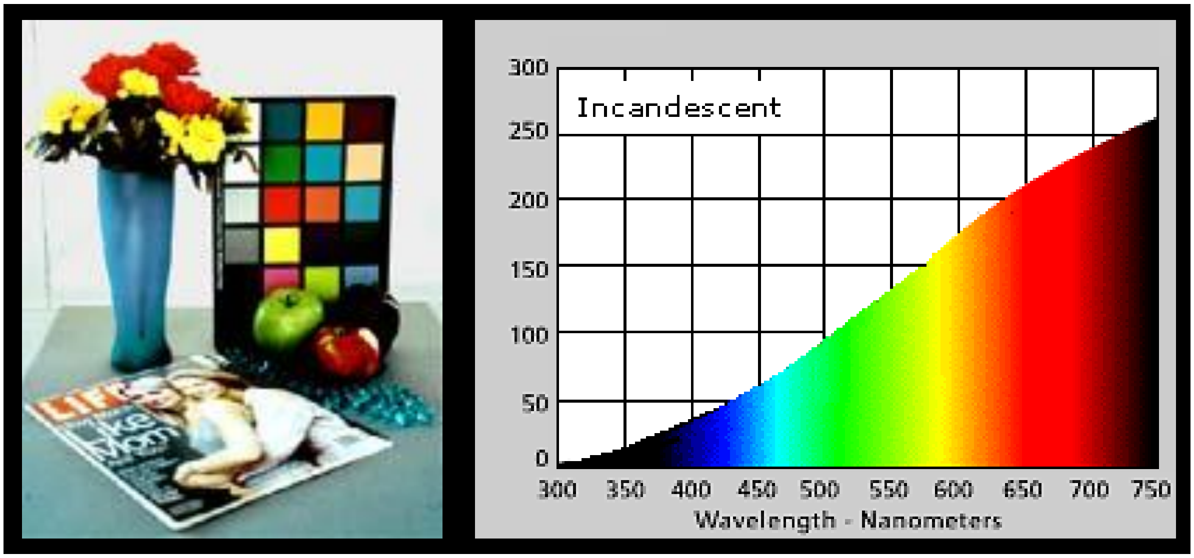

Figure 3. The incandescent light source with CRI of 100 has a more evenly distributed SPD and renders colors more naturally.

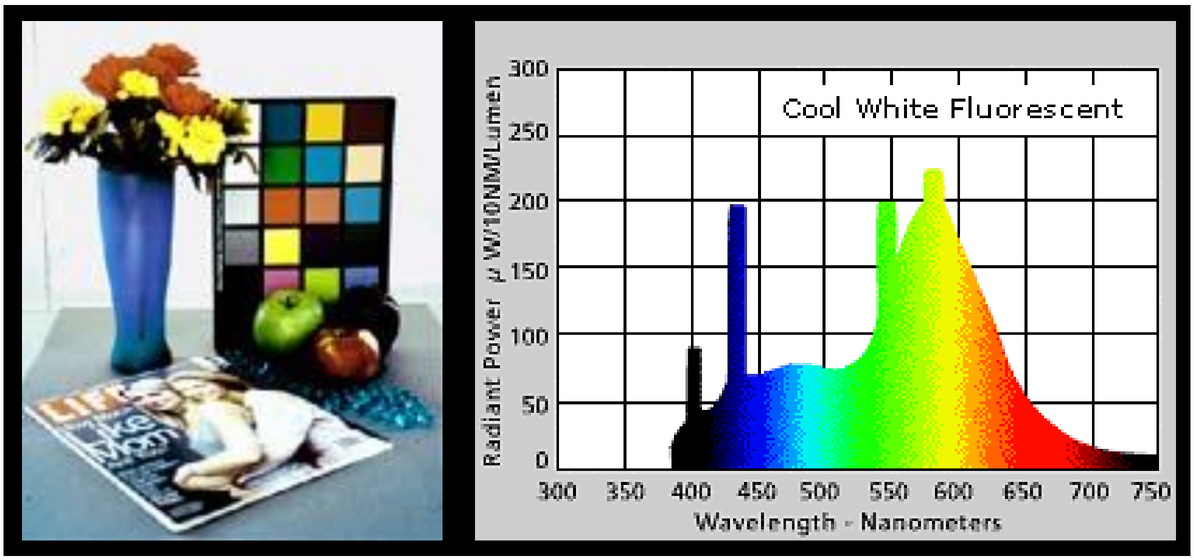

Figure 4. This particular fluorescent lamp has more power in the short wavelength of the visible spectrum (below 450 nanometers) than the incandescent lamp shown above making blue colors appear more vivid and the red colors less vivid.

3.3 Cutter Lighting Survey Data

One of the planned elements of the current study was to conduct a lighting survey of a U.S. Coast Guard cutter and, if possible, make comparisons with a U.S. Navy vessel that has been converted to LED lighting. At the beginning of the project, the study team received information that the CGC MACKINAW (WLBB 30) had replaced its legacy (fluorescent) lighting with LED lights. They accomplished this by converting the existing fluorescent lighting fixtures to accommodate the LED lights. With this development, the team decided that it would be more instructive to make the legacy-LED lighting comparison between U.S. Coast Guard vessels only. The surveys were designed to gather empirical data on the physical output of the lights and to observe any differences in the lighting appearance between legacy and LED lighting. Data collection occurred on the CGC IDA LEWIS (WLM 551), having only legacy incandescent and fluorescent lighting, and the CGC MACKINAW[1]. The spaces in which the illuminance measurements were made are provided in Table 3. Additionally, on the CGC MACKINAW, the team measured the Spectral Power Distribution (SPD), which is depicted in Figure 2 (super-imposed with the SPD for standard commercial fluorescent and incandescent light bulbs). The team documented the visual appearance of the spaces where the measurements were made with photographs taken in the area of the measurements.

Table 3. Illuminance values (in lx) obtained through lighting surveys on CGC IDA LEWIS and CGC MACKINAW.

Testing Location	CGC IDA LEWIS Fluorescent Lighting (in lx)	CGC MACKINAW LED Lighting (in lx)
Engineering Control Center (ECC)	350	450
Galley	980*	600
Engine room	200	465
Berthing (red night light)	14	28
Mess deck surfaces	90-170	457-720
* Lighting configurations and sizes of the galley differed considerably between the two Cutters.		

3.3.1 CGC IDA LEWIS

The initial lighting survey was conducted on CGC IDA LEWIS for a baseline of current shipboard lighting conditions in accordance with *IES Lighting Ready Reference* (1985). Overall assessment of the current lighting revealed that illuminance does not always meet the levels called out in ship's blue prints Naval Engineering Technical Information Management System (NETIMS). Surface Forces Logistics Center (SFLC) also conducted a lighting survey on CGC MORRO BAY (CG WTGB 140', icebreaking tug) in preparation for a service life extension plan (SLEP). Currently, the CG has a fleet of nine 140' WTGBs. Lighting conditions found by SFLC noted results similar to those found on the CGC IDA LEWIS.

[1] During the field lighting surveys, many incandescent fixtures were found to have been replaced by Compact Fluorescent Lamps (CFL).

3.3.2 CGC MACKINAW

RDC conducted a second lighting survey on CGC MACKINAW to determine the illuminance levels of self-installed LED lighting from commercial-off-the-shelf (COTS) sources. CGC MACKINAW readings generally showed an improvement in light output compared with the initial lighting survey conducted on the CGC IDA LEWIS with fluorescent lights. Color temperature readings observed were 4500K Correlated Color Temperature (CCT). MIL1477 spec supplemental requires 4100K with a tolerance of +/- 297K per the Flexible CCT formula listed in ANSI C78.377. To the investigators, the LED lighting on the CGC MACKINAW made the spaces appear "cleaner" than in spaces using other lighting types. The enhanced brightness remained at a comfortable level as well.

3.3.3 Crew Comments Regarding LED Lighting

On CGC Mackinaw, the research team asked crew members to discuss what they thought of the LED lighting. There was consensus that it "made everything look better." A cook in the galley said that the food looked better and that he could see what he was doing better. He joked that he hadn't cut himself since the LEDs had been installed. Upon boarding the CGC Mackinaw, one of the first things the research team noticed was the "bright clean and crisp" lighting, prompting the question if the overhead lighting was the LED lights. It was, and the favorable appearance continued throughout the cutter.

The following figures illustrate the appearance of the lighting installed on the CGC IDA LEWIS and CGC MACKINAW. Although the lighting was adequate on both cutters, Figures 5 and 6 depict lighting differences observed in the ECC.

Figure 5. CGC IDA LEWIS ECC with fluorescent lighting illuminance measured at 350 lx.

Figure 6. CGC MACKINAW ECC with LED COTS lighting measured at 450 lx.

The following figures illustrate the appearance of the LED lighting installed on the CGC MACKINAW.

Figure 7. CGC MACKINAW ECC (working surface 600 lx).

CGC MACKINAW

Figure 8. CGC MACKINAW ECC (instrument surface 450 lx)

Figure 9. Switch Board Control Room (average illuminance 470 lx)

CGC MACKINAW

Figure 10. Engine Room Upper Deck (average illuminance 465 lx).

Figure 11. Galley (working surfaces average 600 lx).

The following figures illustrate the appearance of the LED lighting installed on the CGC IDA LEWIS.

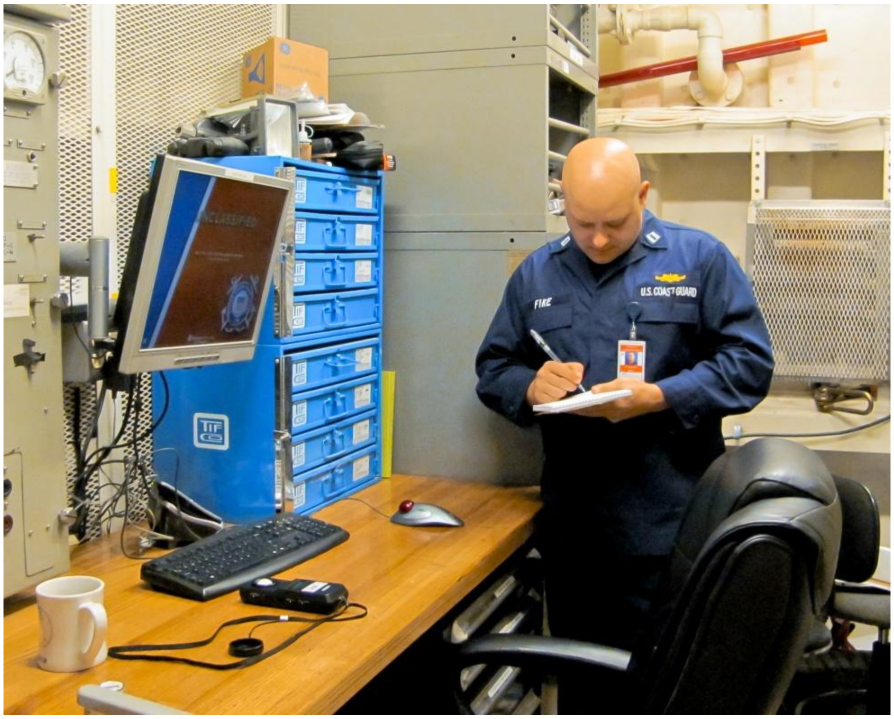

Figure 12. Log Office (working surface 374 lx).

Figure 13. EM Shop (working surface 360 lx).

CGC IDA LEWIS

Figure 14. Light bulb storage takes up valuable space.

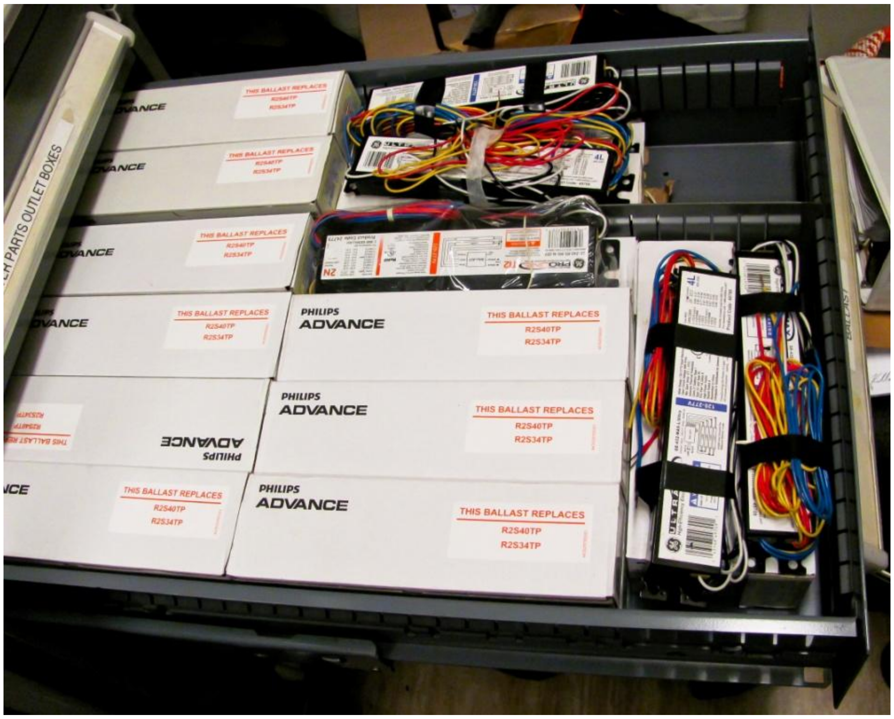

Figure 15. Ballast storage takes up space and adds weight.

4 U.S. COAST GUARD LED COST MODEL

4.1 The Relationship of Cost Factors to Lighting Technology Considerations/Comparisons

A Cost model was developed to determine the return on investment of replacing legacy lighting with LED lighting. This cost model compares the life-cycle costs of up-to four alternative lighting technologies (options) against the life-cycle operation costs of a baseline lighting technology. For the model runs addressed in this report, the baseline lighting technology against which comparisons were made was legacy lighting. Life-cycle operation costs include upfront (initial) investment costs, component replacement costs, and power consumption costs. See Appendix B for instructions for using the Cost Model.

Savings are calculated in the model by subtracting the sum of the upfront investment costs and operation costs of an alternative lighting technology, from the sum of the upfront investment costs (if applicable) and operation costs of the legacy lighting technology. An example of legacy lighting would be the one used in the model run, that being a fluorescent lighting. For fluorescent lighting the configuration would consist of a fixture, a set of light (fluorescent) bulbs, ballast, and any peripheral materials such as wiring. An example of an alternative lighting technology would be LED lighting. For LED lighting, the configuration would consist of a fixture, set of LED light bulbs or light-strips, backup (emergency) power device, a driver card, and any peripheral materials such as wiring. All values and costs specific to a particular lighting technology configuration are referred to in this report and within the model as "technology-relative factors."

Upfront investment costs are the costs incurred when initially installing a lighting technology. Initial investment costs include the purchase cost of the fixture being implemented (if the scenario involves a retrofit that requires replacement of the existing fixture), cost of bulbs or light strips, cost of labor to install or replace, cost of peripheral materials, and disposal costs of any components being removed that require special handling. An example of a disposal cost resulting from special handling would be fluorescent bulbs. Fluorescent bulbs contain mercury and thus cannot just be discarded in the trash. If for some reason, one or more components being removed were exchangeable for a profit, then the value would be treated as a negative when entering the value for disposal cost.

In performing the comparison between legacy lighting and an alternative lighting technology configuration, if the legacy lighting is part of an existing vessel (involving retrofit), then the initial investment cost of the legacy lighting would be considered a sunk cost, and therefore would not be considered when calculating technology investment costs. The exception to legacy lighting being treated as a sunk cost in this scenario would occur if it were possible to remove one or more components of the legacy light being replaced and sell those components for a positive value. If the comparison is being made for a vessel or class of vessels for which construction has not begun and initial lighting materials not procured, then the initial investment cost of legacy (baseline) lighting would be considered in the comparison.

Operation costs for a lighting technology configuration includes power consumed when the light is on (lit), and the replacement of various configuration components as those components reach the end of their life expectancy (determined by total number of hours light is lit). The cost of power consumed differs by whether it is shore-side provided when in port, or it is generated as the result of running ship service generator engines (referred to in the model as cost of power at-sea). The cost of shore-side provided power can differ greatly by regions (homeports). The cost of producing electrical power while the vessel is at sea can be greatly increased if at-sea refueling takes place. Fully burdened cost of fuel as the result of at-sea refueling would not only include the cost of fuel itself, but the cost of transporting the fuel to the location where the at-sea refueling take place.

For any component of a lighting technology configuration that has a life expectancy value (in hours) entered, the model determines when replacement will take place by dividing the life expectancy value by the number of hours the light would be operating per year. If no user-entered life expectancy value is provided for a component, the model will treat that component as not requiring replacement at any point during the model run. It should be noted that while the life expectancy of LED lights is not affected by the number of times it is turned on-and-off, published reports state that the life expectancy of fluorescent and incandescent bulbs are degraded by the bulbs' being turned on-and-off. The model, as currently constructed, does not in itself account for degradation of any lighting technology bulb due to the number of times the bulbs are turned on-and-off.

Most vessel lighting systems are comprised of several light types. Examples of light types that, in combination, may comprise a vessel lighting system would be a vessel using varying numbers of T8, T10, and T1 (Figure 16), and possibly 1-or-2 incandescent light types. Although the cost model could be enhanced to consider an entire vessel lighting system, the version of the cost model released by USCG R&D Center (RDC) in the spring of 2012 analyzes only one light type per run. The light type chosen for the lighting analysis performed for the lighting analysis was the most prevalent for each vessel type considered.

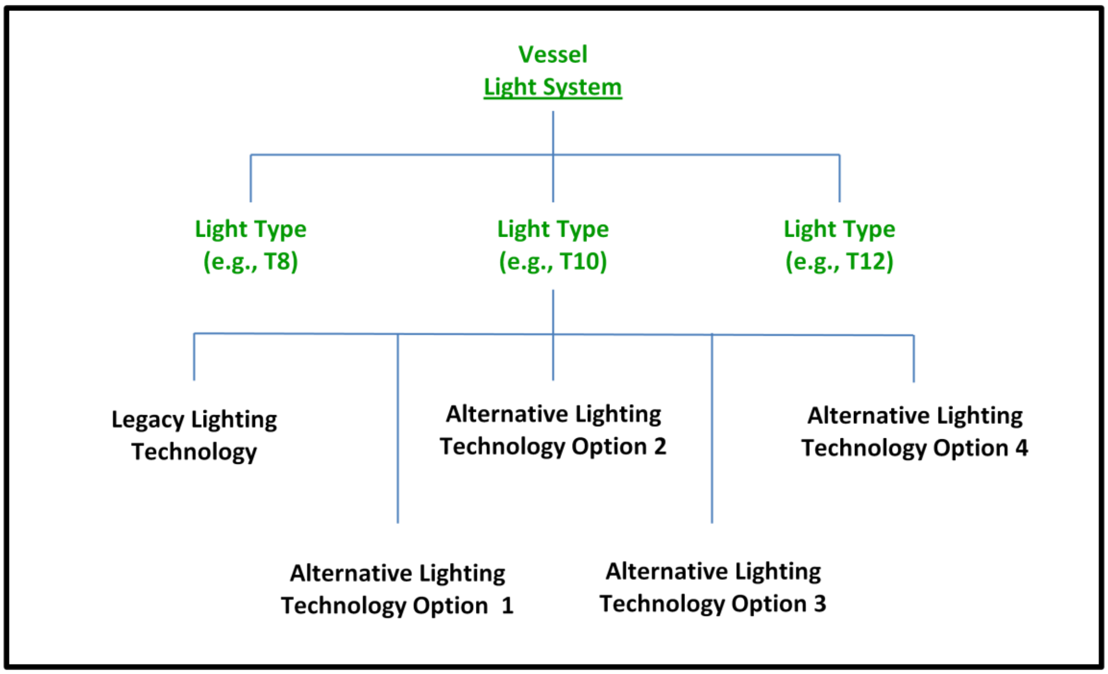

Figure 16. Comparison structure for vessel light system.

In addition to technology-relative factors, the model is driven by a set of common factors. Common factors have an impact on all lighting technology configurations considered in a model run; whereas, technology-relative factors are relative only to the lighting technology configuration with which they are associated.

Figure 17 illustrates how common factors affect all lighting technology configurations and how technology-relative factors affect only the associated lighting technology. In this example the goal is to determine the cost to replace a light bulb for each of the technologies considered. The common cost factor is *Labor Cost Per Hour*, set at $60 for this example. The technology-relative cost factor for this example is *Labor Time Required for Bulb Replacement* (a single bulb). Since technology-relative factors are relative only to their associated lighting technology, there's one entry for *Labor Time Required for Bulb Replacement* associated with the legacy lighting configuration (0.25 hours which means ¼ hour), and one entry for *Labor Time Required for Bulb Replacement* associated with the alternative lighting technology option (0.5 hours which means ½ hour).

In calculating the cost of replacing the legacy light bulb, the common factor *Labor Cost Per Hour* is multiplied by the technology-relative cost factor *Labor Time Required for Bulb Replacement* that is specific to the legacy lighting technology configuration. The result of that calculation ($60 * 0.25) is a labor cost of $15 per bulb replacement. For the alternative lighting technology option, the common factor *Labor Cost Per Hour* is multiplied by the technology-relative factor *Labor Time Required for Bulb Replacement* that is specific to the alternative lighting technology option. The result of that calculation ($60 * 0.5) is a labor cost of $30 per bulb replacement.

COMMON COST FACTOR
Labor Cost Per Hour: $60.00

TECHNOLGY-RELATED COST FACTOR
Labor Time Required for Bulb Replacement
Legacy Configuration: 0.25 Hrs
Alternative Lighting Tech Option 1: 0.50 Hrs

COST TO REPLACE BULB FOR LEGACY LIGHTING	COST TO REPLACE BULB FOR ALTERNATIVE LIGHTING TECH OPTION 1
Labor Cost Per Hr [$60]	Labor Cost Per Hr [$60]
multiplied by	multiplied by
Labor Time for Legacy Lighting [0.25]	Labor Time for Alt Tech Option [0.50]
equals	equals
$15 to Change Single Bulb	$30 to Change Single Bulb

Figure 17. Example of common factor in determining costs.

As with any cost model, the validity of the results is dependent upon the data used in the model. The research team acquired commercial costs of legacy and LED bulbs and fixtures directly from vendors. Electric power costs were extracted from base electrical power cost by regions since individual Cutter inport costs were unattainable. The cost of underway power generation came from the Alaris report (2011). The procedures and time required for fixture retrofitting to accommodate LED installation was available from discussions with the Electrician Mates on the CGC MACKINAW as well as from a time compliance technical order (CGTO PG-85-00-40-S TCTO) that detailed the steps and process taken by the CGC MACKINAW. The number of ship's lighting fixtures for the model were obtained through ship configuration listings. RDC used the Cutter employment standards manual to populate the cost model based upon cutter class.

4.2 Example Model Results

A 270' WMEC with a homeport in Key West, FL was utilized to run analysis on due to its impending replacement and the potential to impact the ship's design. Factors in-put to the model were gathered from current market research, Cutter employment standards, energy audits conducted by Alaris (2011), and MILSPEC available products ROM pricing. Results are shown taking all factors and calculating the total life cycle of the lighting currently installed and four alternatives.

The results are displayed in tables and graphically for ease of reading and visual comparison. The listing of model results provided are; upfront (initial) investment, payback period (years), estimated total savings, Net Present Value (NPV) of estimated total savings, investment rating based on NPV result, annual energy consumption (kilowatt hours), annual energy savings (kilowatt hours) and cumulative labor (graphed only). Figure 18 shows input factors on the DE-light page of the cost model. Full user instructions for data entry are located in Appendix B.

LIGHT TYPE:	77.4				
NUMBER OF FIXTURES:	841				
		OPTION 1	OPTION 2	OPTION 3	OPTION 4
	LEGACY LIGHTING	LED Commercial BULB ONLY	Commercial FIX/BULB	LED MILSPEC BULB-ONLY	MILSPEC eplacement fixture
CONSIDERATION STATUS => INVESTMENT COST	NON FACTOR	FACTOR	FACTOR	FACTOR	FACTOR
FIXTURE					
CONSIDERATION STATUS => INVESTMENT COST	NON FACTOR	NON FACTOR	FACTOR	NON FACTOR	FACTOR
CONSIDERATION STATUS => REPLACEMENT COST	NON FACTOR	NON FACTOR	NON FACTOR	NON FACTOR	NON FACTOR
CONSIDERATION STATUS => POWER USAGE	NON FACTOR	NON FACTOR	NON FACTOR	NON FACTOR	NON FACTOR
FIXTURE PURCHASE COST		$ -	$ 350.00	$ -	$ 476.00
PERCENTAGE FIXTURE PURCHASE COST					
REDUCTION IN COST OVER TIME					
TIME					
ADDITIONAL MATERIALS COSTS (e.g., wiring)	$ -	$ 10.00	$ 25.00		$ 10.00
LABOR TIME for INSTALLATION	0.00	0.50	3.00	0.20	0.50
NUMBER OF BULBS IN FIXTURE	2	2	2	2	2
WATTAGE CONSUMPTION					
(Note: This specific to fixture, no bulbs)					
LIFE EXPECTANCY					
END OF LIFE DISPOSAL COST	$ 0.34				
FIXTURE INSTALLATION-RELATED QUESTIONS					
[Yes = Y or No = N]					
DOES FIXTURE COST INCLUDE BULB(S)?	n	N	y	N	y
DOES FIXTURE COST INCLUDE					
BALLAST OR BACKUP-POWER DEVICE?	y	N	Y	Y	y

Figure 18. Example model in-put area.

An example of model outputs for all operations and cost considerations is displayed in Figure 19. MILSPEC replacement bulb only option is more costly due to shorter life expectancy verses MILSPEC fixture that is an engineered LED system. ROI for recommended MILSPEC replacement lighting compared to legacy systems is 8.5 years. LED lighting energy consumption compared to current installed lighting is another appealing factor in the pursuance for Coast Guard carbon footprint reduction. Reducing energy consumption measured in kWh comparisons is shown below in Figure 20.

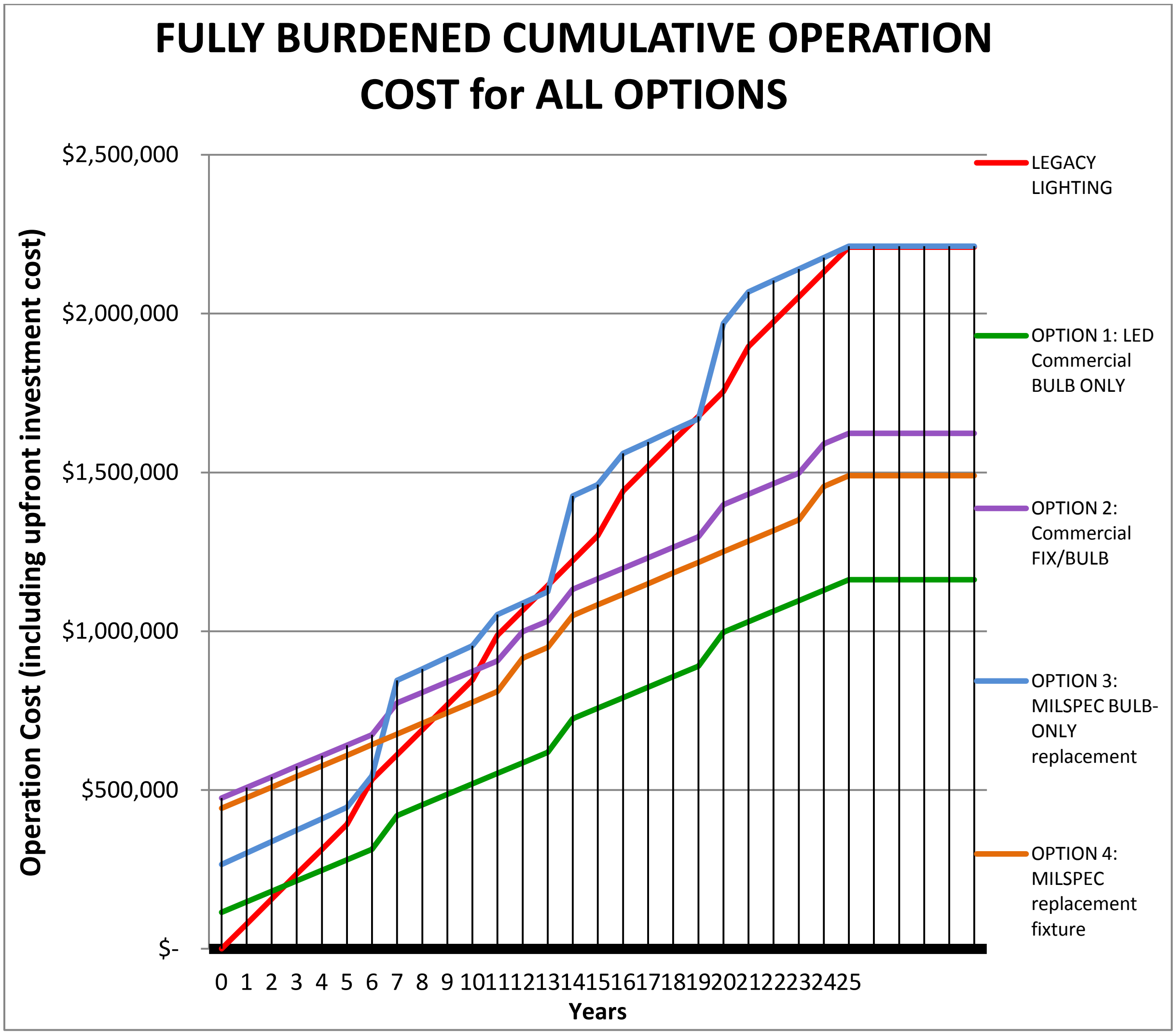

Figure 19. Example ROI model results.

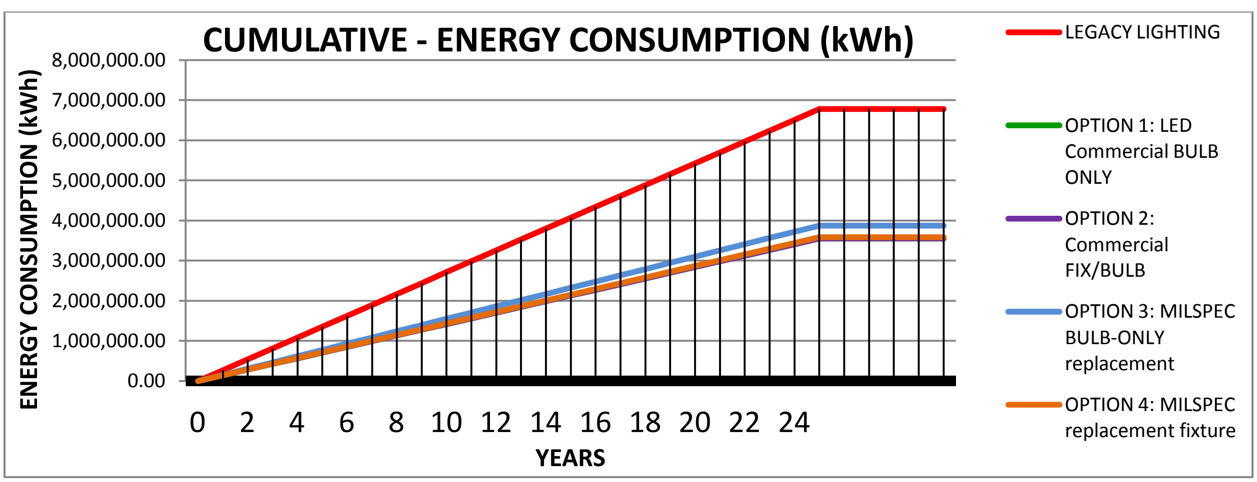

Figure 20. Example total energy consumption.

Also included is a cumulative labor comparison as shown in Figure 21. Labor hours decrease due to the lessend maintence requirements of LED lighting are shown graphically. Steps in graph reflect maintenance actions occuring such as bulb or ballast change outs.

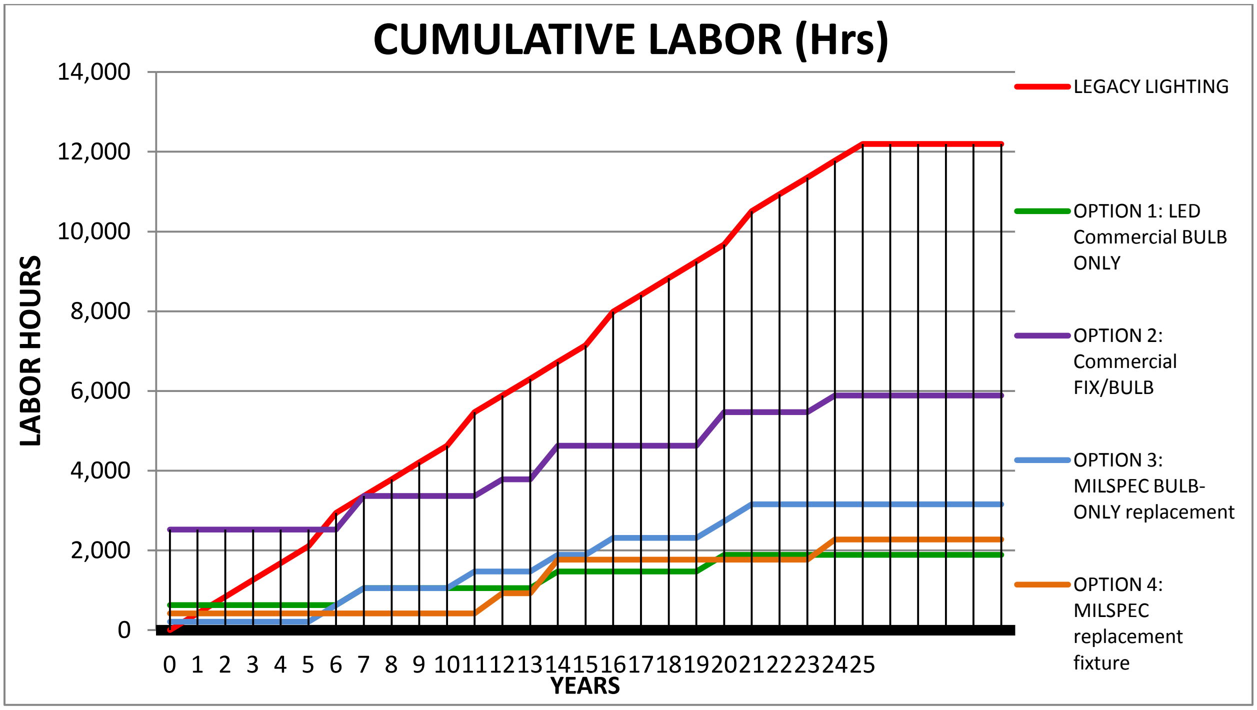

Figure 21. Example cumulative labor hours.

4.3 Factor Sensitivity Analysis Model Runs

A cost model is only an approximation of reality (Render & Stair, Jr., 1988). Therefore, exploring the sensitivity of the solution (e.g., payback period and estimated total savings) to changes in input data is an important part of analyzing the results. A sensitivity analysis was performed in which a WMEC class vessel with a homeport in Key West, Florida served as the baseline. Key West was chosen as the homeport for the baseline vessel because its shore-side electrical cost appears to be in the midpoint range of ports where WMEC class vessels reside. (Since the CG is in the initial design phase for a replacement of the 270 WMEC class vessel, it was selected to serve as possible candidate to compare against new construction.)

The goal of the sensitivity analysis was to determine how much payback period, estimated total savings, NPV of estimated total savings, percentage savings in labor hours, and percentage in annual power consumption reduction would be affected by changes to user-provided input data. Table 4 contains common factors from a WMEC in Key West, FL. In performing the analysis for each of the user-provided input data, incremental changes were made to the baseline value in increments of 10, running from a 50% reduction in the value to a 50% increase in the value.

Table 4. Common factors requiring user-provided input for a sensitivity analysis.

Common Factors	Factor Baseline Value
Days At-Sea	180 Days
Labor Rate	$60.00 Per Hour
Discount Rate (critical to calculation of NPV)	2.70 %
Cost of Power At-Sea	$0.4200 Per kWh
Cost of Power In-Port	$0.0966 Per kWh
Number of Fixtures	841

Where the legacy lighting technology configuration requires ballast for every fixture, the alternative lighting technology configuration considered in the model runs (LED lighting) requires emergency backup power devices for only about 20% of the fixtures. Therefore, during sensitivity runs for the factor *Number of Fixtures*, the value for number of backup power devices installed for each percentage change in number of fixtures was 20% of the number of fixtures. For example, a 50% decrease from the baseline in the number of fixtures would be 421 (from half of baseline common factors in table 4) equating to 84 backup power devices installed (20% of the 421fixtures)

Table 5. Technology-relative factors requiring user-provided input for a sensitivity analysis.

Technology-Relative Factors	Factor Baseline Value
Fixture Purchase Cost	$476.00 each
Per Bulb Purchase Cost	$25.00 each
Bulb Power (Energy) Consumption	11 Watts
Labor Time – Bulb Replacement	0.50 hours (30 minutes)
Bulb Life Expectancy	100,000 hours
Driver Card Purchase Cost	$40.00 each
Driver Card Life Expectancy	90,000 hours
Backup (Emergency) Power Device Purchase Cost	$50.00 each
Backup (Emergency) Power Device Life Expectancy	90,000 hours

4.3.1 Payback Period

The most significant effect on payback period as a result of factor input value changes were *Fixture Purchase Cost* and *Bulb Power (Energy) Consumption*. With a 50% decrease in value to $238.00 for *Fixture Purchase Cost*, the payback period decreased by 39% to 5.16 years, and with a 50% increase in value to $714.00, the payback period increased by 73% to only 14.61 years. With a 50% decrease in value to 6 *Watts for Bulb Power Consumption*, the payback period decreased by 25% to 6.33 years, and with a 50% increase in value to 17 Watts, the payback period only increased by 85% to 15.60 years.

Taking a conservative economic perspective, with a 30-year life expectancy for the WMEC class vessel considered in the sensitivity model runs, a payback period of 10 years or less (33% of 30 years) would be reasonably prudent. *Fixture Purchase Cost* has a 10.47-year payback period at a 30% increase in value ($618.80 for each fixture). As can be seen in Figure 22, the payback period rises sharply when the *Fixture Purchase Cost* is increased by 40-and-50 percent due to the higher costs in price. If there is a threat that the purchase cost of the fixture could rise at some point before the procurement occurs, a closer look would need to be taken with this analysis. With the advancement and growth in technology in lighting the chances of an increase of prices diminish as maturity rises.

The payback period for Bulb Power Consumption is 10.21 years at the point its value increases by 30%, and would still be a reasonably safe venture up to a 40% increase in power consumption (wattage rating). After the 40% mark, payback period rises sharply (Figure 22). Such an increase in power would be counter to current trends in this technology.

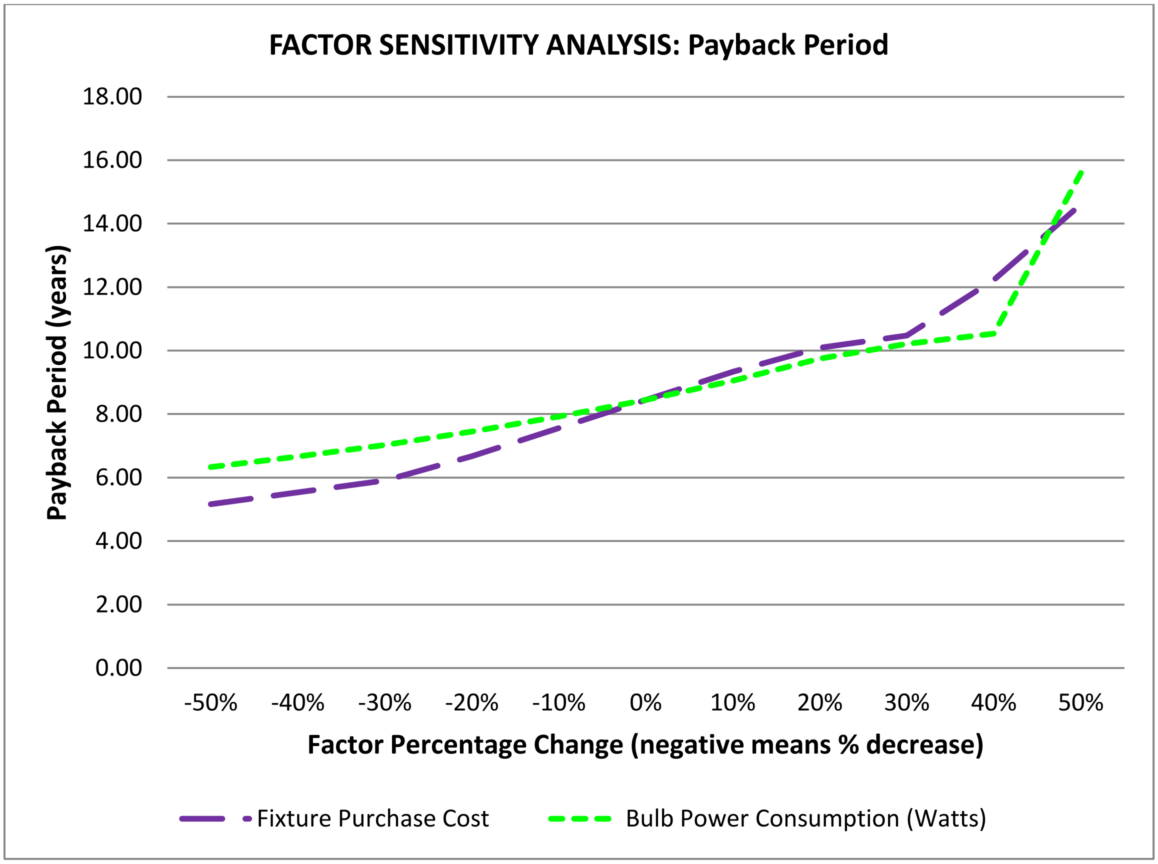

Figure 22. Sensitivity analysis: Payback Periods for Fixture Purchase Cost and Bulb Power Consumption.

All other factors considered in the sensitivity model runs experienced small-to-no rises in payback period at either end of the 50% increase/decrease of baseline value. Of these, a 50% reduction in the baseline value for *Cost of Power At-Sea*, which equated to $0.21 per kWh, resulted in a payback period increase of 24% (10.45 years). A payback period of 10.45 years 35% of 30 years, is considered reasonably safe. *Cost of Power At-Sea* was the next greatest sensitive factor behind the sensitivity of *Fixture Purchase Cost* and *Bulb Power Consumption*. Unless there is a sharp increase or decrease in the price of fuel the cost of power generation at sea will remain stable.

4.3.2 Estimated Total Savings

The most significant effect on estimated total savings as a result of factor input value changes were *Bulb Power (Energy) Consumption*, *Number of Fixtures*, and *Cost of Power At-Sea*. A 50% increase in value of *Bulb Power Consumption* to 17 watts resulted in a 58% drop in savings from that realized by the baseline value however as LED technology grows this trend has actually diminished. That drop in savings equates to a total savings over a 30-year period of $397,979. A substantial positive savings over the long run would still be achieved. As can be seen in Figure 23, realizing a substantial positive at the lowest point of estimated total savings is still a significant amount as well for *Number of Fixtures* and *Cost of Power At-Sea*.

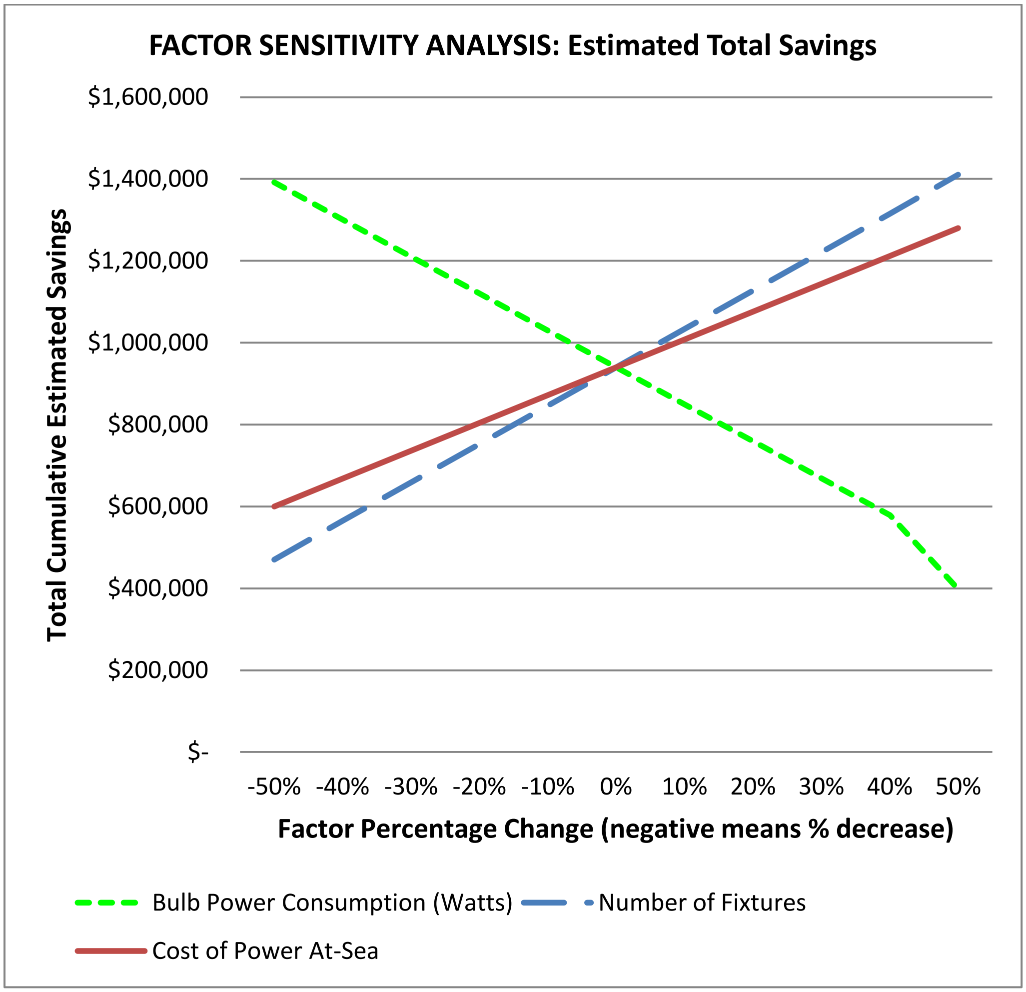

Figure 23. Sensitivity analysis: Payback Periods for Bulb Power Consumption, Number of Fixtures, and Cost of Power At-Sea.

Although the estimated total savings would still be substantial when the baseline value for *Bulb Power Consumption* is increased by 50% to 17 Watts, one has to keep in mind that the $397,979 total savings is achieved by the vessel life expectancy reaching no less than 30 years. Figure 24 shows the savings realized at yearly points along the vessel consideration's life expectancy. Note that before the payback period is achieved (15.6 years), the cumulative (total) savings would be negative (a loss in dollars). What this figure is telling you is for a 50% increase in *Bulb Power Consumption* one needs to determine the risk that the actual life expectancy may not only come in short of 30 years, but slide down towards the 15.6-year point. This increase in power consumption is not likely. From the beginning of this study new LED drivers have been introduced to the emerging market that efficiency and power consumption has had the inverse outcome.

The reason for the dips and rises seen in Figure 24 has to do with the fact that this cost model takes into consideration life cycle costs. The dips and rises reflect component replacements taking place. A sharp rise indicates there is either more than one bulb replacement occuring for the legacy lighting technology configuration in that timeframe, or multiple components of the legacy lighting technology configuration are being replaced in that timeframe. A sharp drop indicates that a component replacement within the alternative lighting technology configuration is taking place.

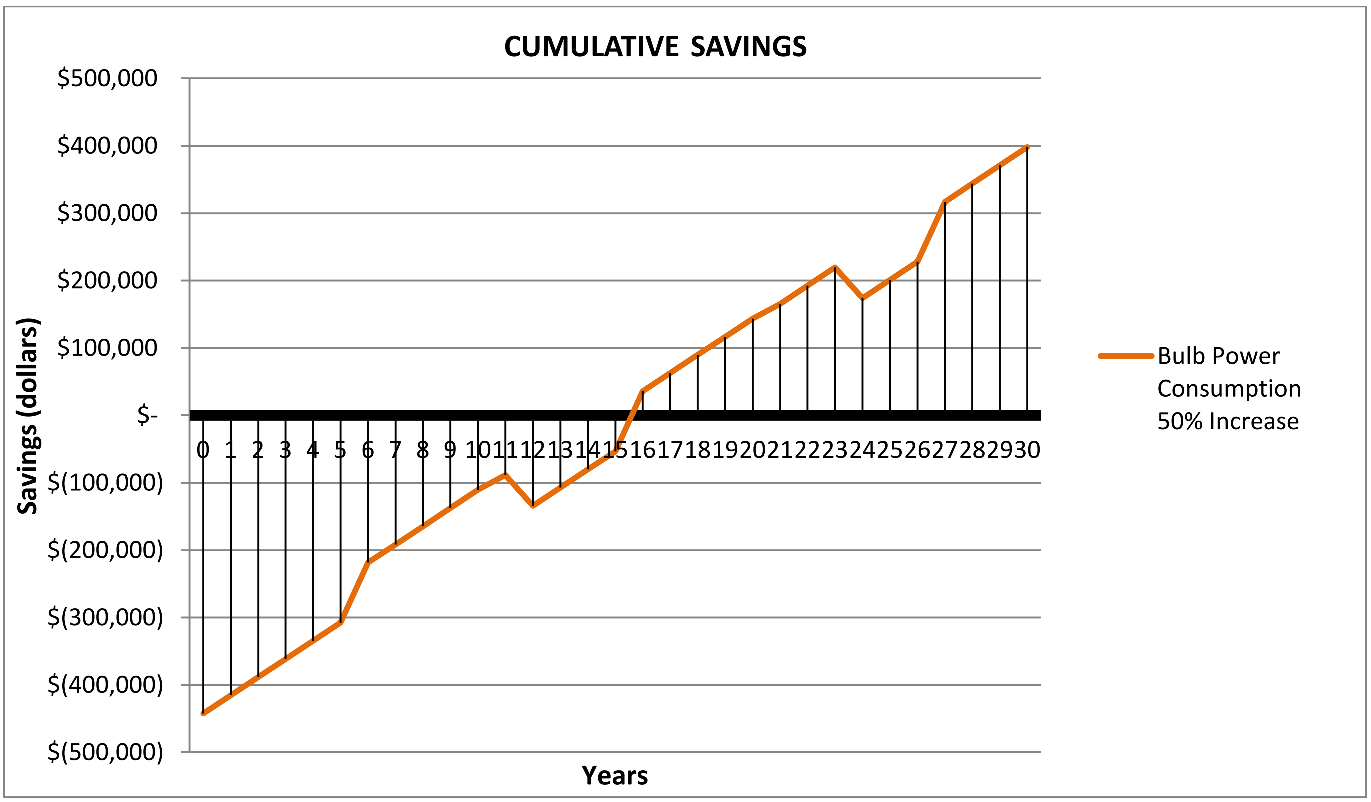

Figure 24. Savings for bulb power consumption.

The risk of not achieving a positive total savings based on actual life of the vessel is relatively lower for *Number of Fixtures* and *Cost of Power At-Sea*. That is because each of their payback periods at the 50% point-of-concern is in the 10-year range or less.

4.3.3 NPV of Estimated Total Savings

The most significant effect on NPV of estimated total savings as a result of factor input value changes were *Bulb Power Consumption*, *Number of Fixtures*, *Cost of Power At-Sea*, *Fixture Purchase Cost*, and *Discount Rate*. A 50% increase in the *Bulb Power Consumption* that brings the value to 17 watts results in a 72% decrease from the baseline of estimated total savings when taking NPV into consideration (Figure 25). Although the result in the NPV of total estimated savings is still positive, as was stated in the discussion of total estimated savings, the NPV of total estimated savings with a 50% increase in wattage of the bulb is realized as long as the actual vessel life expectancy is 30 years.

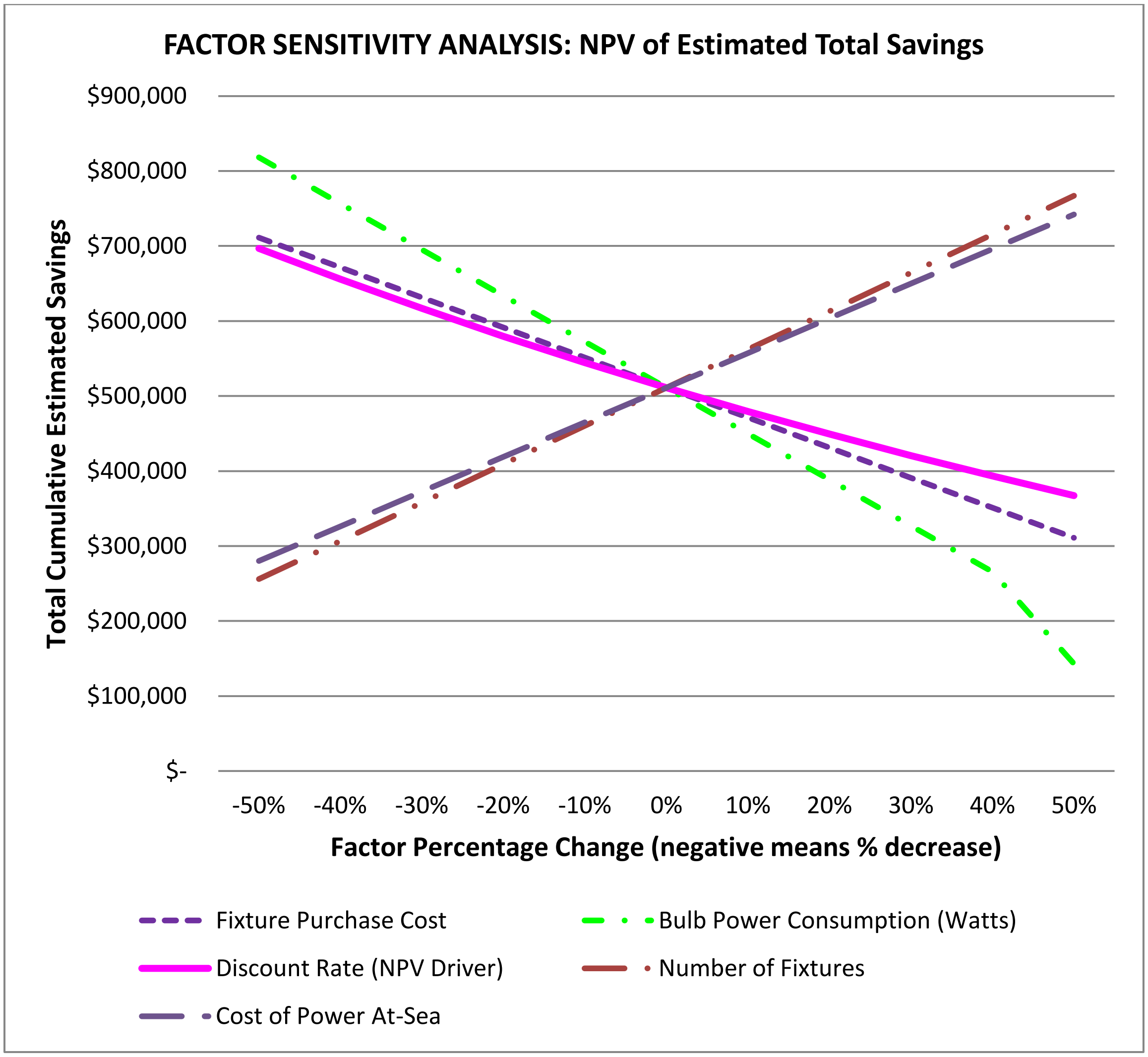

Figure 25. Factor sensitivity analysis: NPV of estimated total savings.

Figure 26 reinforces the concern about risk of investment if the wattage rating increased to 50% greater than the baseline. The graph shows that payback period when taking NPV into consideration is around the 20-year mark. Under this scenario there is even a greater need to be certain the vessel life will be no shorter than 20 years in order to recoup the investment. Fortunately it is highly unlikely that the wattage rating of the alternative lighting technology bulb would be greater than the baseline value used in the model run, and actually the inverse would be true.

There would be similar concerns regarding NPV of estimated total savings if the value for *Cost of Power At-Sea* were to increase beyond 30%, and if decreases in *Fixture Purchase Cost* or *Number of Fixtures* for the alternative lighting technology configuration were to exceed 20% and 30%, respectively.

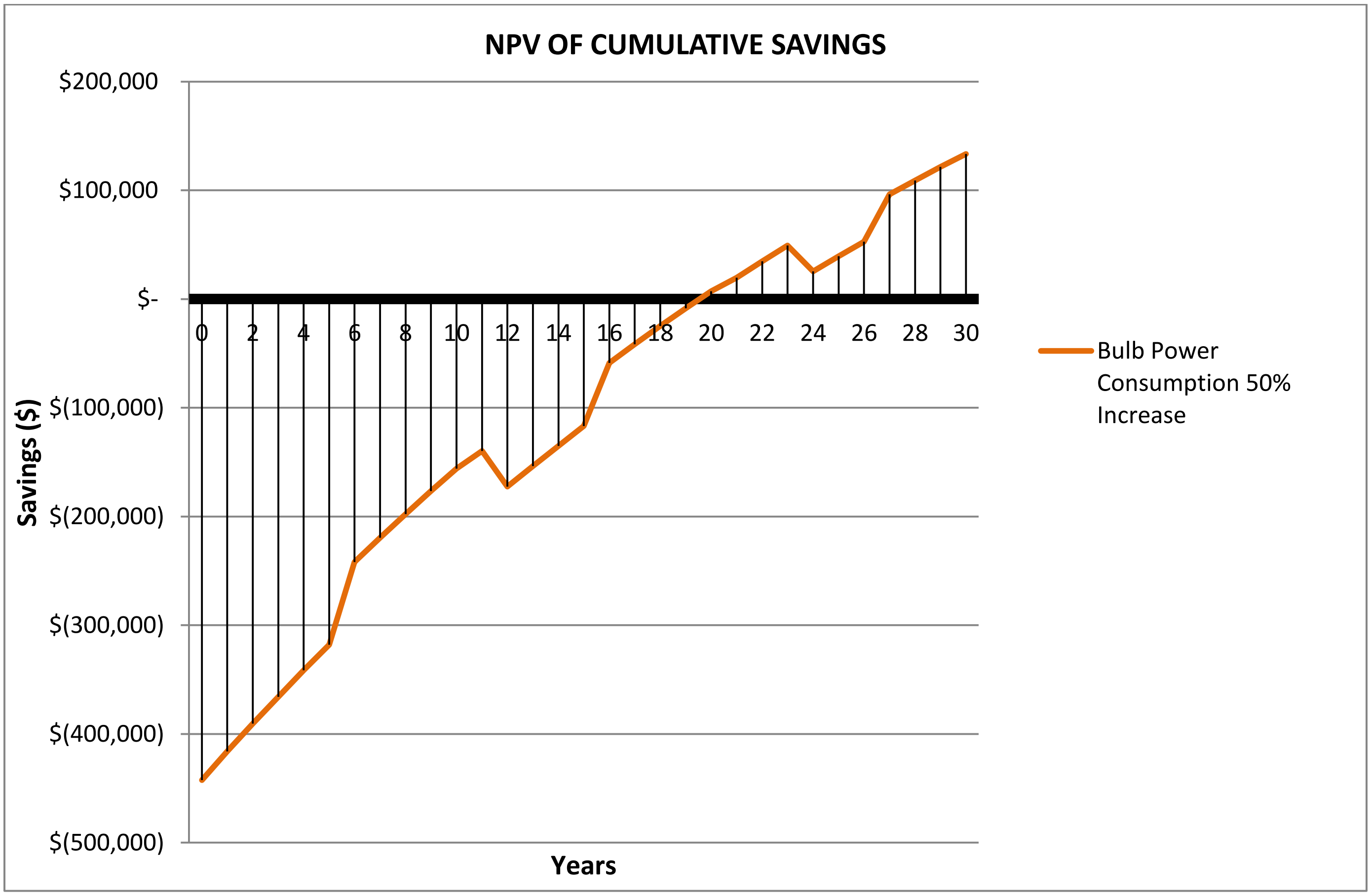

Figure 26. NPV of cumulative saving and payback for bulb power consumption 50% increase.

Since the value for the common factor *Discount Rate* drives the calculation of NPV of estimated total savings, percentage changes in its value relative to the baseline should logically have an impact on NPV of estimated total savings. Figure 27 shows the effect of percentage changes in the *Discount Rate*. An increase in the *Discount Rate* of 50% over the baseline results in a 28% drop in NPV of estimated total savings, a drop to $367,338 (Figure 27). This is still a sizable savings, but the key is that the actual vessel life expectancy be no shorter than 30 years. When the *Discount Rate* is increased by 50%, some level of savings is realized as long as the actual life expectancy of the vessel exceeds about 13 years.

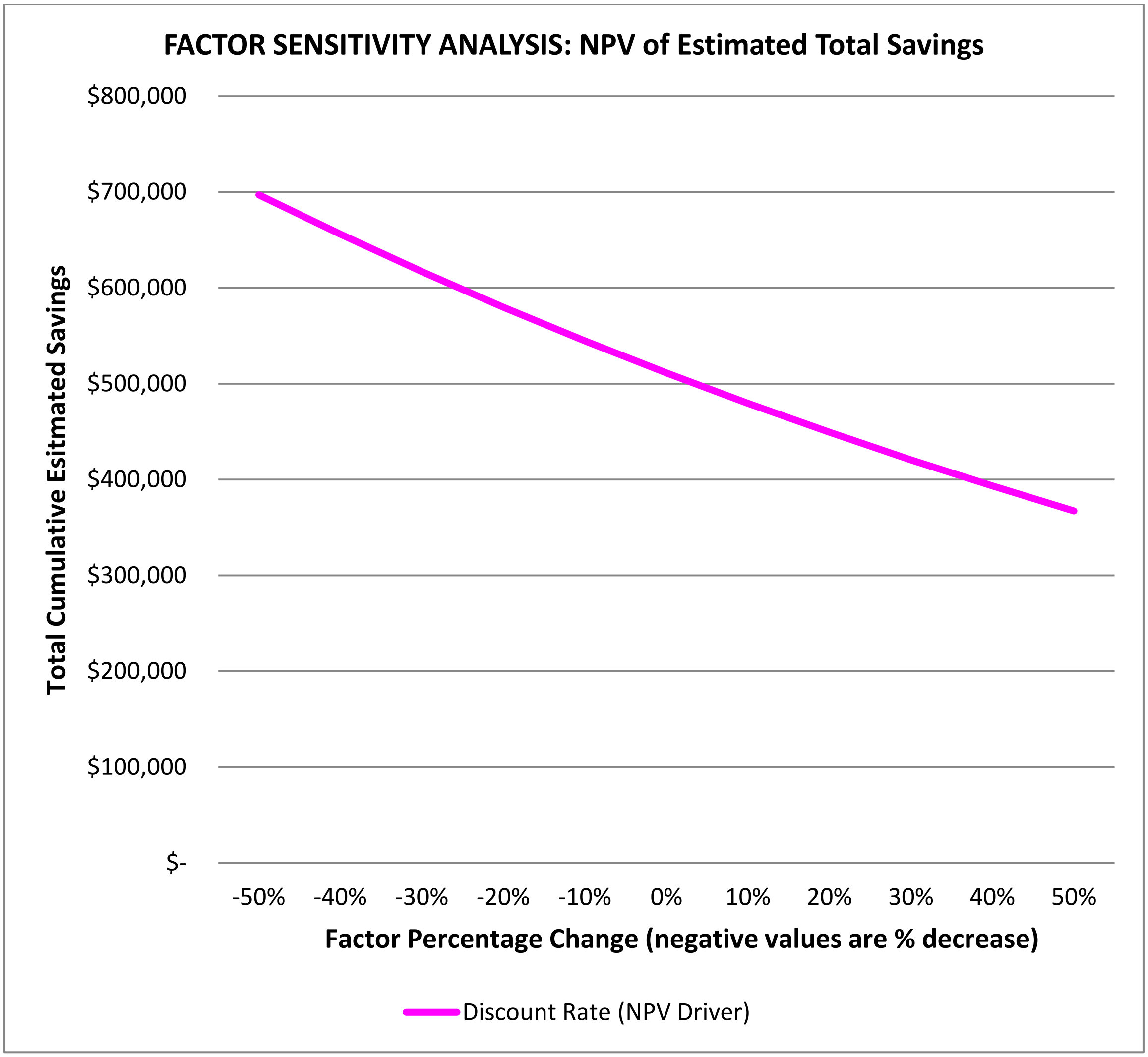

Figure 27. Effect of percentage changes in the discount rate on total cumulative estimated savings.

4.3.4 Percentage Savings in Labor Hours

The only factors for which a percentage change in their baseline value had an effect on percentage savings in labor hours were *Bulb Life Expectancy*, *Bulb Labor Time*, *Days at Sea*, and *Backup Power Device Life Expectancy*. As can be seen in Figure 28, the effect of percentage changes in value at the most extreme ends on any of the 4 factors was very small. *Bulb Life Expectancy* had the greatest impact on percentage savings in labor hours when decreasing the value. That is because the bulb needs be changed more often as the life expectancy value is reduced. *Bulb Labor Timer* has an effect as its value increases. That is because the total amount of time it takes to replace a bulb when it reaches its life expectancy is greater as the value increases.

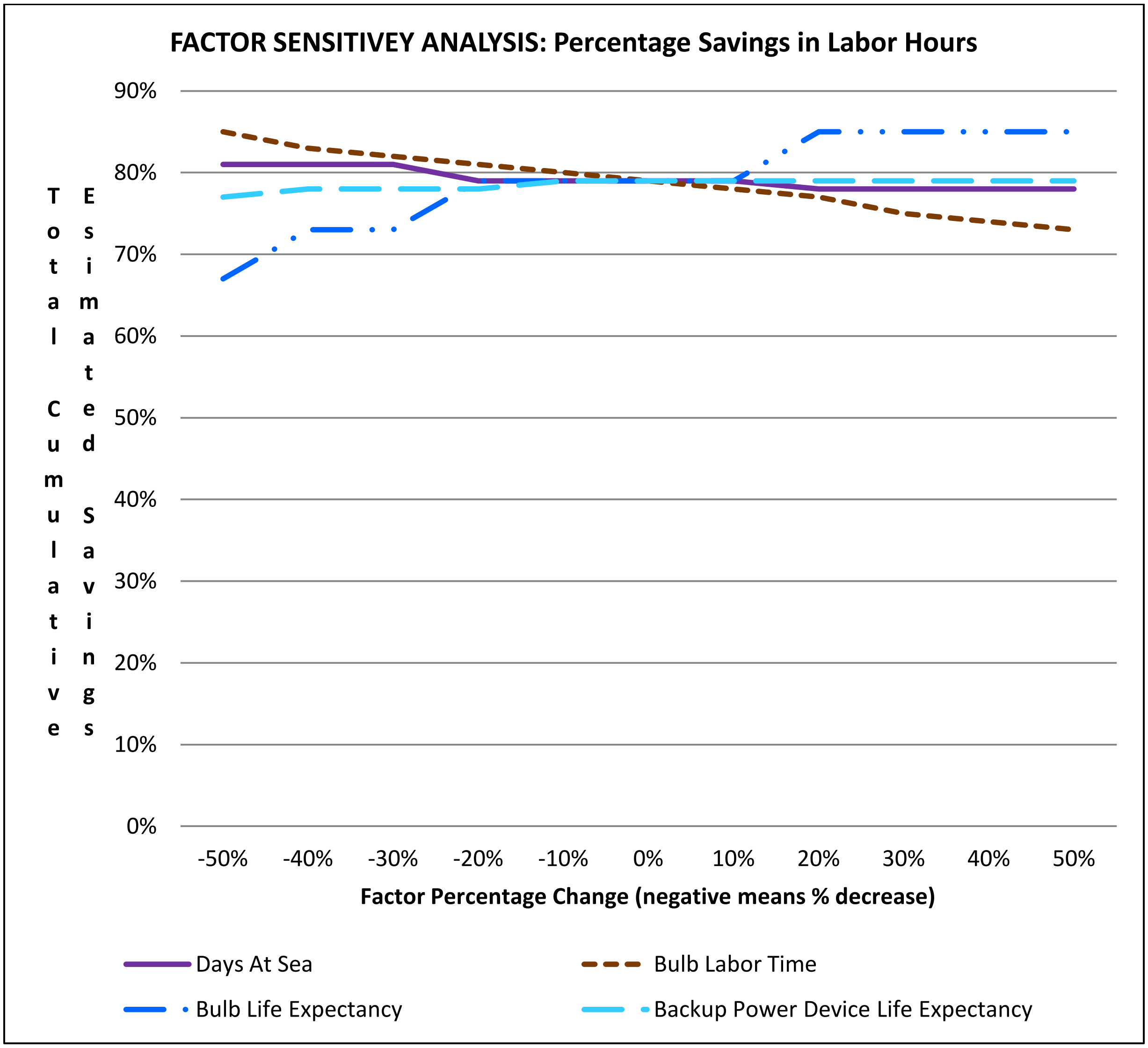

Figure 28. The effect of percentage changes of bulb life expectancy, bulb labor time, days at sea, and backup power device life expectancy on labor hours.

4.3.5 Percentage in Annual Power Consumption Reduction

The only factor that had any effect on percentage savings as result of change in baseline value was *Bulb Energy Consumption*, and this was a significant effect (Figure 29). Fortunately, as previously observed, the wattage rating of the bulb for the alternative lighting technology is very unlikely to exceed its baseline wattage rating.

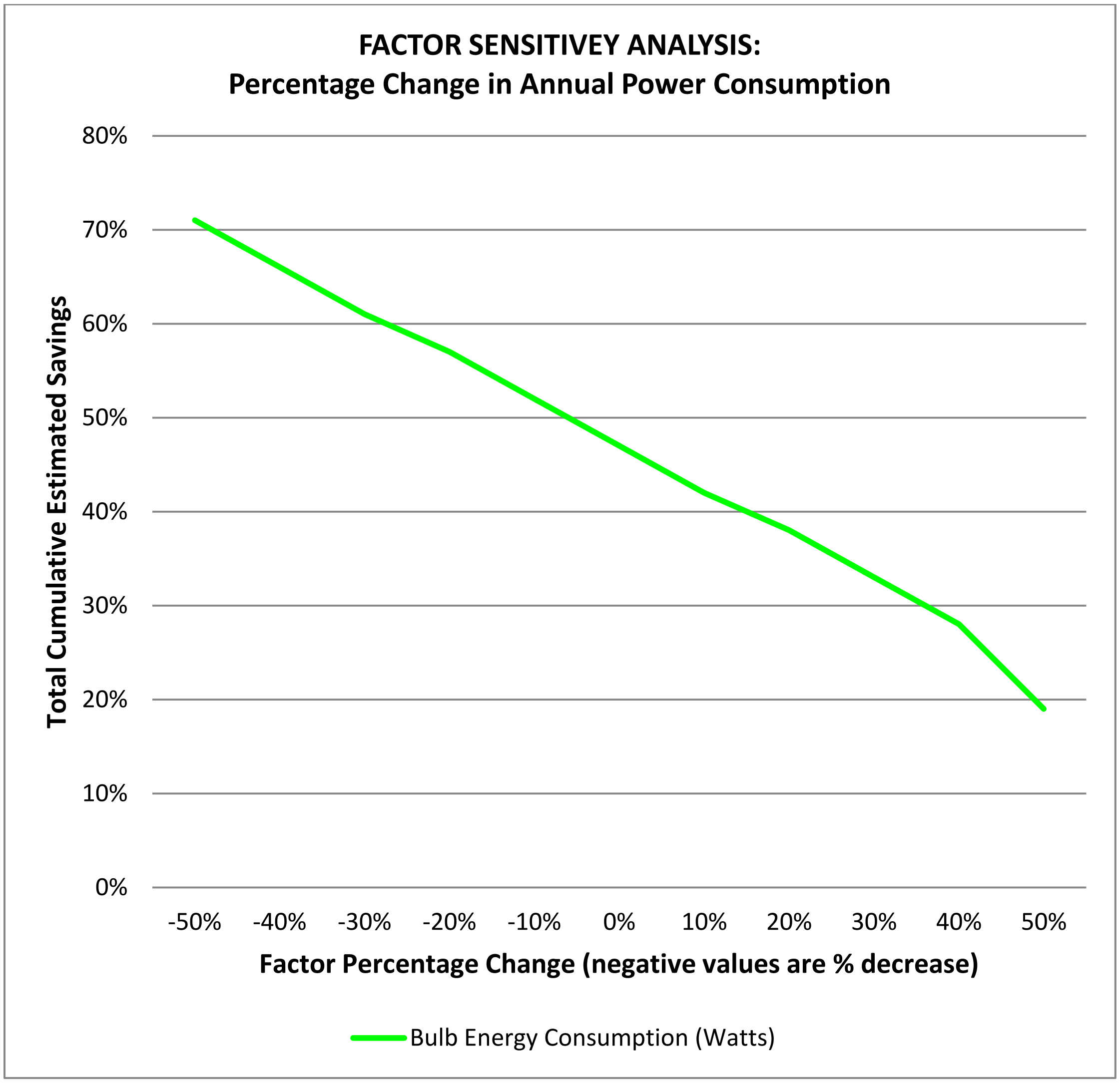

Figure 29. Effect of percentage change in annual power consumption on total estimated savings.

4.3.6 Summary of Factor Sensitivity Analysis

In making a determination as whether-or-not to make a capital investment, from a financial perspective analysts look to 3 indicators, those being payback period, estimated total savings, and NPV of estimated total savings. A WMEC class vessel was one of two classes of vessels considered in model runs. The goal was to determine if one or both of those class vessels would prove from a cost savings perspective to be good investment candidates for installation of LED lighting over traditional (referred to as legacy lighting) fluorescent lighting. For those runs, a MILSPEC LED lighting technology was considered. Results of the model runs for both classes of vessels had a favorable investment rating for all 3 investment indicators.

The next step in the financial analysis was to perform a factor sensitivity analysis to determine what the impact would be to the model results as factor values changed over a percentage range, the range chosen was a negative 50% change to a positive 50% change in value relative to the baseline value (performed in increments of 10%). A number of common and technology-relative factors were analyzed. The 270' WMEC class with a homeport in Key West, Florida, was chosen as the subject vessel for the factor sensitivity analysis. Results of the sensitivity analysis showed a favorable rating was maintained for all 3 capital investment indicators at the extremes of the analysis (a 50% change in baseline factor values).

Five (5) of the 15 factors studied in the sensitivity analysis runs showed great sensitivity to extreme changes in their values, although as stated, none of the capital investment indicators showed anything less than favorable at those extremes. The 5 factors were Fixture Purchase Cost, Bulb Power Consumption, Cost of Power At-Sea, Number of Fixtures, and Discount Rate. Bulb Power Consumption is the wattage rating of the bulb. For the MILSPEC LED, the risk of the wattage rating creeping up-or-down from its advertised rating should be little-to-none. For the factor Number of Fixtures, there is no change at the extremes in payback period from the payback period of its baseline. The change occurs for its estimated total savings and NPV of estimated total savings, which means the greater the number of fixtures to be converted, the greater the total savings that will be realized.

Percentage value changes in Fixture Purchase Cost has a significant impact because the higher the fixtures cost, the greater the total amount of the upfront (initial) investment costs will be incurred. This in turn means the longer it will take to reach the breakeven point, the payback period for the investment. Doing a more detailed analysis of the extreme where degradation of its capital investment indicators have the greatest degradation, that being a look at its cumulative savings for each year over the vessel life span (30 years) considered in the model run, it becomes obvious that payback period relative becomes the key concern. Thus it is important at the extremes that the confidence level be high in the expected life expectancy of the vessel.

Cost of Power At-Sea has a significant impact because it has a high cost to produce, costing about 3-to-4 times the amount it costs to obtain power from most U.S. commercial/public power grids. For the cost to produce power at sea, either fuel costs will have to significantly decrease, or the engine or generator's efficiency in generating power would have to improve. Another concern that can be derived from the sensitivity of the factor Cost of Power At-Sea is if the vessel's time in homeport were to increase significantly.

Discount Rate has an impact only, and a significant one at that, on NPV of estimated total savings. The significant impact is because Discount Rate is the key driver in the calculation of NPV of savings. This would be a definite concern if it is believed the Discount Rate could rise to a level exceeding a 50% increase in value over the baseline run in the model, but it must also be stated that the WMEC class vessel was used as a basis for the runs as the Coast Guard is in the initial design phase for a WMEC class replacement. Since vessels that are not in the process of being constructed and no legacy lighting technology configuration components have been purchased, initial investment costs would have to be considered. For these model runs the legacy lighting technology's investment costs were not considered to give the result a very conservative view. If the investment costs of the legacy lighting technology were considered in the model runs, the payback period would have been lowered substantially.

5 CONCLUSIONS AND RECOMMENDATIONS

This study was conducted to assess the potential to reduce shipboard lighting expenses through the use of LED lighting as a replacement to incandescent and fluorescent lighting, referred to as legacy lighting. Particular attention was paid to fluorescent lighting because it is the predominant lighting source on current CG Cutters. The study included three primary approaches: a review of USN ship lighting, lighting surveys conducted on CG Cutters, and the development of a CG lighting cost model to assess the payback period, if any, of transitioning to LED lighting. The following sections provide summaries of the findings of the study:

5.1 Conclusions

5.1.1 Review of US Navy Ship Lighting

The USN determined in 2001 that legacy lighting was expensive and accounted for approximately 1/3 of the ship's fuel consumption (Lovins, 2001). (Due to its operations, the USN has continued to use burdened fuel costs as the metric for evaluating shipboard lighting expenses.) Research followed to determine if cheaper, more innovative lighting systems could be used to provide shipboard lighting. One series of studies considered distributed lighting fed by a common source (Cizek, 2009); although lighting sources and fiber optics of the time were not sufficient to provide adequate lighting intensities. LED technology advanced sufficiently that by 2008, the USN decided to evaluate it as a transitional technology. Business cases broadly based upon naval operations, rising costs of fuel, and decreasing costs of LEDs were developed at the Naval Postgraduate School (Cizek, 2009; Freymiller, 2009). The results of these studies and ONR funded LED development projects led the USN to initiate a series of studies to convert from legacy to LED lighting. Many ships and submarines will be retrofitted by 2014. Navy ship systems managers consider LED lighting to be a proven technology that has progressed well beyond the research and development stage. In addition to fuel cost savings, an important factor in the USN decision to transition to LED lighting is the resulting reduction in carbon emissions (green operations).

5.1.2 CG Lighting Surveys

The CG study team conducted two lighting surveys. The lighting survey conducted on the CGC IDA LEWIS (WLM 551) measured illuminance from legacy fluorescent lighting. The lighting survey conducted on the CGC MACKINAW (WLBB 30) measured illuminance from COTS LED lighting in corresponding ship's spaces. These illuminance values were compared in Table 3. Although the power consumption of LED lights is about one-half that of the fluorescent lights, the illuminance values were generally much higher for the LED lights. The study team took particular notice of the appearance of the LED lighting. It provided even, bright illumination without harshness or tinting. Improvement in color balance was explained by the increased broadband spectrum of the LED light compared with the narrow band spikes of the fluorescent light (Figure 2). The study team concluded that the LED lighting quality was comparable, if not better, than fluorescent lighting.

5.1.3 Cost Model

A cost model was created in Microsoft Excel that compared the life cycle costs of as many as four alternative lighting technologies with the life cycle costs of the baseline lighting technology, fluorescent lighting. Calculations included upfront (initial) investment costs, component replacement costs, and power consumption costs. Configurations of the alternative lighting technologies included the fixture, lighting bulbs/strips, backup power devices, a driver card, and peripheral material such as wiring. These factors that were specific to a lighting technology were termed "technology-relative factors." Technology-relative factors included the type of light, fixture cost, life expectancy of the specific bulb, power consumption of the type of light, and disposal costs. Factors that were associated with all the lighting technologies were termed “common factors” and included factors such as labor cost, annual light usage, and cost of electrical power in the same operating area.

The cost model yielded key results such as upfront/initial investment cost, payback period for the alternative lighting technology, estimated total savings, and the Net Present Value of the savings spread over the years of vessel use. A series of factor sensitivity analysis model runs were then conducted for a notional 270 WMEC class vessel with its homeport in Key West, Florida. The factor sensitivity analyses determined how much the payback period, estimated total savings, NPV of the estimated total savings, percentage savings in labor hours, and percentage in annual power consumption reduction would be affected by incremental changes (10%) that spanned -50% to 50% of the value of technology-relative and common factors.

Key results of the WMEC class analyses included (30 years of vessel life assumed):

- MILSPEC light technology is more mature than COTS LED technology.
- The estimated payback period for MILSPEC LED installation was approximately 8.5 years not accounting initial investment.
- Though the MILSPEC LED installation is more expensive that COTS type LEDs, a 30 year cumulative savings of approximately $400,000 per vessel was seen even with 50% increases in expense factors.
- The most significant effect on estimated total savings determined by the factor sensitivity analyses were *Bulb Power (Energy) Consumption*, *Number of Fixtures*, and *Cost of Power At-Sea*
- A 30% decrease in *Fixture Purchase Cost* lowers the payback period to 6 years. A 30% decrease in *Bulb Power Consumption* lowers the payback period to 7 years (Figure 19). Inversely a 30% increase in *Fixture Purchase Cost* or *Bulb Power Consumption*, the payback period rises to approximately 10.5 years.
- The savings accrued do not follow a smooth progression. Sudden drops in the savings curve occur when component replacements are required. As the lifespan of the LED technologies lengthens, these deviations in annual savings will occur less frequently over the 30 year lifespan of the vessel.

5.2 Recommendations

Based upon researching the USN transition to LED lighting, the lighting surveys conducted on CG Cutters, and the results of the cost model runs, the following recommendations can be made:

- LED lighting should be installed on all new construction Cutters.
- Any cutter having more than 10 years of service life projected should be considered for re-fitting to MILSPEC approved LED lighting. MILSPEC lighting will not produce the savings of COTS LED lighting; however, the additional testing and measures taken to reduce unwanted electrical noise (dirty power) on the ship’s circuits makes this lighting option preferred until COTS lighting becomes more standardized.
- Due to the higher electricity prices in Guam, Hawaii, and Alaska, the return on investment will be greater in these areas. Testing or implementing LED lighting transition should be applied to such areas first.
- A TCTO should be drafted to authorize MILSPEC approved light fixtures as replacements.
- A good candidate for a test platform is the 140 WTGB because the planned SLEP for this platform is imminent and a current line item on the project is LED lighting.

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APPENDIX A. NAVSEA APPROVAL NOTICE; MIL-DTL-16377 SUPPLEMENT SPECIFICATIONS FOR SOLID STATE LIGHTING (SSL)

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
2531 JEFFERSON DAVIS HWY
ARLINGTON VA 22242-5160

IN REPLY REFER TO

9330
Ser 05Z32/031
AUG 2 2 2008

From: Commander, Naval Sea Systems Command
To: Distribution

Subj: APPROVAL NOTICE; MIL-DTL-16377 SUPPLEMENT SPECIFICATIONS FOR SOLID STATE LIGHTING (SSL)

Ref: (a) Military Specifications MIL-DTL-16377H; General Specification of Lighting Fixtures, and Associated Parts for Shipboard use, dtd 2 Aug 96

Encl: (1) NSWCCD Philadelphia ltr 9300 Ser 939/058 w/enclosures dtd 15 July 2008

1. Reference (a) is the current specification for Naval shipboard lighting fixtures and associated parts for both new construction and in-service Fleet. This specification consists of incandescent and fluorescent lighting equipment of specific design tailored for Naval shipboard environment. In view of the reliability, durability, and cost efficient advantages of the Solid State Lighting (SSL) technology as stated in enclosure (1), we are now expanding the reference (a) requirement to include SSL for Naval shipboard applications.

2. Enclosure (1) included approved Supplement Specification for SSL which identified the qualification requirement, and example test requirement.

3. Prior to the official update of reference (a) to include SSL requirement, the First Article Testing (FAT) process for SSL is modified as follows: interested vendors shall submit test procedures with formal request for testing to NAVSEA 05Z32 and NSWCCD Philadelphia Code 93 prior to testing. The request shall include a description of the luminaire, energy efficiency discussions, drawing showing full dimensions and weight, a schedule detailing the qualification process, and a test plan. Successful SSL luminaire FAT shall consist of fulfilling all requirements and passing all applicable tests described in reference (a) and the Supplement specification for SSL. Vendors with a luminaire that meets the applicable requirement shall formally submit all test results and reports in a company letter to NSWCCD Philadelphia Code 93. Eligible SSL luminaires will be issued a Navy "Approved For Use" letter after meeting all applicable requirement.

4. Navy point of contact for MIL-DTL-16377 Supplement Specification for Solid State Lighting or the example test requirement is Mr. R. Zalewski, Code 939, 215-897-8121 or Mr. E. Markey, code 938, 215-897-7226. NAVSEA 05Z32 point of contact is Mr. Chuk Eng, 202-781-3776.

for KHOSROW MONIRI
by direction

Subj: APPROVAL NOTICE; MIL-DTL-16377 SUPPLEMENT SPECIFICATIONS FOR SOLID STATE LIGHTING (SSL)

Distribution:
SNDL FKP7 (ALL NAVSHIPYDS)
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NSWCCD Philadelphia (Code 91, 93, 936, 937, 938, 939)
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CO RMC
NAVAIR 678 (Jerry Terrell)
DLA-IS Philadelphia (Jay Kratz, Joyce Pezick)

Ira Baskin
L.C. Doane Company
55 Plains Road
P.O. Box 975
Essex, CT 06426
860-767-8295
irab@lcdoane.com

Brent Gathright
Pauluhn Electric MFG
1616 North Main Street
Pearland, Texas 77581
281-485-4311
bgathright@pauluhn.com

Lothar Budike
Light-Pod Inc.
The Navy Yard; Quarters K
1123 Admiral Peary Way
Philadelphia, PA 19112
lbudike@light-pod.com

Michael Fusco
LED Specialist
7A Main Street
Kings park, NY 11754
mfusco@ledspecialists.com

Subj: APPROVAL NOTICE; MIL-DTL-16377 SUPPLEMENT SPECIFICATIONS FOR SOLID STATE LIGHTING (SSL)

Lex Lapidus
US Pioneer Inc.
P.O. Box 472065
Tulsa, OK 74147-2065
llapidus@uspioneer.net

Roger Buelow
Energy Focus Inc.
32000 Aurora Road
Solon, Ohio 44139
rbuelow@energyfocusinc.com

C3I, Inc
Charles J. Wagner
Center Square, D4
11 Merrill Industrial Drive
Hampton, NH 03842
603-929-9989
cwagner@c3i-usa.com

RSL Fiber Systems
Giovanni P. Tomasi
19 Zeya Drive
Coventry, CT 06238-0727
860-742-2910
gptomasi@skylergroup.com

John Toman
Oxley, Inc.
31 Business Park Drive
Branford, CT 06405
203-433-1502
j.toman@oxleyinc.com

. Su031

DEPARTMENT OF THE NAVY
NAVAL SURFACE WARFARE CENTER
CARDEROCK DIVISION

NAVAL SHIP SYSTEMS
ENGINEERING STATION
5001 S. BROAD STREET
PHILADELPHIA, PA 19112-1403

IN REPLY REFER TO
9300
Ser 939/058
15 July 2008

From: Commander, Naval Surface Warfare Center, Carderock Division-Ship Systems Engineering Station, Philadelphia, PA 19112-5083
To: Commander, Naval Sea Systems Command, SEA 05Z32
Attn: Mr. Khosrow Moniri

Subject: **APPROVAL REQUEST, MIL-DTL-16377 SUPPLEMENT SPECIFICATION FOR SOLID STATE LIGHTING (SSL)**

Ref: (a) MIL-DTL-16377H, 02 Aug 96, Detail Specification; Fixtures, Lighting, and Associated Parts: Shipboard use, General Specification

Encl: (1) MIL-DTL-16377 Supplement Specification for Solid State Lighting (SSL), 09 Jun 08
(2) EXAMPLE Solid State Lighting (SSL) Testing Requirements, 02 Jul 08

Purpose

The purpose of this letter is to provide formal submission of Encls (1) and (2) to SEA 05Z32 in support of advancing the testing and qualification of Solid State Lighting (SSL) illumination systems on naval ships and submarines.

Background

The commercial lighting industry is in the process of transitioning from incandescent and fluorescent light sources to Light Emitting Diode (LED) based lighting. The continued and rapid improvement in LED technology has made LED light sources affordable, reliable, durable, long life, and cost efficient when associated with the maintenance of traditional light sources. Shipboard SSL is considered the integration of LEDs devices into a luminaire suitable for vessel installation. The physical design of SSL systems provides a greater resistance to shock and vibration, significantly increasing the luminaires rated life. LEDs exhibit very long operational life characteristics, typically 50,000 hours or longer. The NAVSEA Warfare Centers have been pursuing the evolution of LED lighting and consider the technology mature and an excellent candidate for transition to the naval fleet. NAVSEA shares the same vision and goals as the Department of Energy by supporting lighting technologies with "minimal energy usage, environmental impact, durability and recyclability, and are manufactured with modern technology and practices to ensure our Nation's continued economic vitality and energy security".

Discussion

The MIL-DTL-16377 Supplement Specification Encl (1) will serve as the requirements and verification tool for NAVSEA qualification of shipboard SSL systems. The document will not stand alone, but will be used as a supplement to the existing base detail lighting specifications MIL-DTL-16377 Ref (a). The supplement discusses the definition of SSL, and provides a new classification (Type III) applicable to only SSL systems. Non-Government publications

APPROVAL REQUEST, MIL-DTL-16377 SUPPLEMENT SPECIFICATION FOR SOLID STATE LIGHTING (SSL)

from Rensselaer Polytechnic Institute, DOE Energy Star, Illuminating Engineering Society of North America (IESNA), and American National Standards Institute (ANSI) are referenced through the document for measurement methods and commercial specifications.

The Subject: requirements section simplifies the photometric requirement for chromaticity of white, red, amber, blue, and NVD friendly cyan lighting. Ambient and accelerated lumen maintenance testing has been included to ensure SSL systems are designed for long life applications. The fail-safe circuit design requirement addresses the need for alternative path circuits for open or failed LEDs. The verification section discusses the need for official procedures and reports for each first article, comparison, and conformance tests. Shipboard power interface requirements are addressed and separate test methods are identified for power quality and voltage transient spike. Addition requirement and verification procedures are listed within the document certifying the SSL luminaire will qualify for shipboard installation.

The EXAMPLE Solid State Lighting (SSL) Testing Requirements Encl (2) will be used as a generic slant sheet used to identify general and first article requirements for SSL luminaires designed as replacements for T12 legacy luminaires. The document lists the general requirements and uses a table for identifying the test method and the required sequence for a number of testing methods.

<u>**Conclusion**</u>

In order to prevent the exclusion of the newly developed Solid State (Type III) lighting for near term Naval shipboard applications, we recommend their approval by using the base specification and supplement specification as an interim qualification vehicle until the base specification can be properly updated.

Prior to the base specification update, we also recommend the First Article Testing (FAT) process for SSL be modified to require interested vendors to submit all test procedures with a formal request for testing to NAVSEA 05Z32 or a NAVSEA designated activity prior to testing. The request shall include a description of the luminaire, energy efficiency discussions, drawings showing dimensions and weight, a schedule detailing the qualification process, and a test plan. Successful SSL luminaire FAT shall consist of fulfilling all requirements and passing all tests described in the MIL-DTL-16377 base document and the MIL-DTL-16377 Supplement Specification for SSL. Vendors with a luminaire that meets the applicable requirements shall formally submit all test results and reports as enclosures in a company letter to NAVSEA. Eligible SSL luminaires will be issued a Navy "Approved For Use" letter after meeting all specification requirements.

NSWCCD-SSES point of contact for MIL-DTL-16377 Supplement Specification for Solid State Lighting (SSL) or the EXAMPLE Solid State Lighting (SSL) Testing Requirements is R. Zalewski, Code 939, (215-897-8121) or E. Markey, Code 938, (215-897-7226).

Pete Tahopoulos

P. Tahopoulos
Manager, Advanced Electric Power
Systems Branch, Code 939
By direction

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NAVSEA NAVAL SEA SYSTEMS COMMAND

APPROVAL REQUEST OF MIL-DTL-16377 SUPPLEMENT SPECIFICATION FOR SOLID STATE LIGHTING (SSL)

ENCLOSURE (1)

MIL-DTL-16377 Supplement Specification for Solid State Lighting (SSL), 09 Jun 08

15 July 2008

NAVSEA
NAVAL SEA SYSTEMS COMMAND

MIL-DTL-16377 SUPPLEMENT SPECIFICATION
FOR SOLID STATE LIGHTING (SSL)

This specification is approved for use by the Naval Sea System Command and is available for use by all Departments and Agencies of the Department of Defense. The requirements for solid state lighting described herein shall consist of this document and MIL-DTL-16377.

1. SCOPE

1.1 **Scope.** This specification covers Solid State Lighting (SSL) luminaires and associated parts for legacy replacement and new luminaire development. It supports SSL luminaires for detail and general illumination systems on naval ships and submarines; it shall serve as a supplement to MIL-DTL-16377.

1.2 **SSL definition.** SSL utilizes Light Emitting Diodes (LEDs), Organic Light Emitting Diodes (OLEDs), or Polymer Light Emitting Diodes (PLEDs) as sources of illumination rather than electrical filaments or gas. The term "solid state" refers to light emitted from a block of solid semiconductor compared to a glass sphere or tube. The physical design of SSL systems provides a greater resistance to shock and vibration, significantly increasing the luminaires rated life.

1.3 **Extent.** SSL may function as a replacement for Fluorescent (Type I) and Incandescent (Type II) lighting systems and shall meet the same Type I and II specifications currently identified in MIL-DTL-16377. Classifications shall be Detailed (Class 1) and General (Class 2) illumination. In the event of any conflict between MIL-DTL-16377 and this supplement, the latter shall govern.

1.4 **Classification.** SSL luminaires are of the following types and classes.

Type III – Solid State
Class 1 – Detail illumination
Class 2 – General illumination

2. APPLICABLE DOCUMENTS

2.1 **General.** The documents listed in this section are specified in sections 3 and 4 of this specification. This section does not include documents already cited in MIL-DTL-16377. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all MIL-DTL-16377 specification requirements.

2.2 **Government specifications and standards.** The following documents and standards form a part of this document to the extent specified herein.

MIL-STD-461 - Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.

MIL-STD-3009 - NAVAIR Interface Standard; lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible.

2.3 **Non-Government publications.** The following documents and standards form a part of this document to the extent specified herein.

LIGHTING RESEARCH CENTER, RENSSELAER POLYTECHNIC INSTITUTE;
ALLIIANCE for SOLID STATE ILLUMINATION SYSTEMS and TECHNOLOGIES (ASSIST)
LED Life for General Lighting;
(Definition of Life) Volume 1, Issue 1, February 2005
(Measurement Method for LED Components) Volume 1, Issue 2, February 2005
(Measurement Method for LED systems) Volume 1, Issue 3, August 2007

DOE ENERGY STAR Program Requirements for Solid State Lighting Luminaires
Eligibility Criteria – Version 1.0, Dated 12 October 2007

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ILLUMINATING ENGINEERING SOCIETY of NORTH AMERICA (IESNA)
IESNA LM-79-08 – Approved Method for the Electrical and Photometric Measurements of Solid State Lighting Products

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)
ANSI C78.377-2008 – Specifications for the Chromaticity of Solid State Lighting Products

SOCIETY of AUTOMOTIVE ENGINEERS (SAE)
Aircraft Recommended Practice (ARP) 4392 and 5825

3. REQUIREMENTS

3.1 **Specifications.** Type III solid state luminaire requirements shall be specified herein and shall be in accordance with MIL-DTL-16377 requirements for Type I and II, Classes 1 and 2.

3.2 **First article testing.** Testing waivers and extensions can be granted by NAVSEA on a case by case basis for a complete luminaire family if a manufacturer completes the recommended tests in the required sequence and provides rational to substantiate identical functionality.

3.3 **Drawings.** Prerequisite to submission of first article testing the vendors shall submit evidence of satisfactory drawing approval by NAVSEA. Manufacturing drawings shall be reviewed and approved for all luminaires and components furnished under this specification. Drawings shall be in AutoCAD, or other approved format, and include physical dimensions, parts lists, and wiring diagrams.

3.4 **Components.** The luminaire shall incorporate field replaceable components for the following items; LED drivers, LED arrays, lens, and batteries if used. Replaceable components shall be serviceable using simple hand tools. All components shall be shown on the luminaire drawing and subject to NAVSEA approval.

3.5 **Electrical connections.** Connections between the solid state device and drivers circuits shall be the quick disconnect plug-in type with built-in locking mechanism. Incoming power circuit conductors and internal wiring conductors shall terminate on one terminal board. Terminal boards, lugs, and circuit boards shall comply with MIL-E-917 requirements. Wire nuts and wire compression connectors are not permitted within the luminaire enclosure, all electrical connection hardware shall be shown on the luminaire drawing and subject to NAVSEA approval.

3.6 **Salt spray.** Metallic luminaires and shock mounts applicable to weather deck installation, and/or exposure to salt water environments, shall withstand the salt spray test as specified in MIL-DTL-16377 without corrosion. No evidence of corrosion shall be present and no adverse impact to the luminaire heat sink shall be apparent at the end of the testing sequence.

3.7 **Environmental conditions.** Luminaires and components shall be designed to operate within an ambient temperature range of - 25 deg. C to 50 deg. C with relative humidity between 20 and 100% non-condensing.

3.8 **Testing laboratories.** Photometric testing for candela distribution, brightness, and chromaticity shall be performed by an ENERGY STAR certified or recognized National Voluntary Laboratory Accreditation Program (NVLAP) testing laboratory. Electrical testing for power interface, power quality, voltage transient spike, EMI, and EMP shall be performed by an independent testing laboratory, shock and vibration testing shall be conducted at a Navy approved facility. Independent laboratory test procedures shall be reviewed and approved by NAVSEA prior to testing. Additional qualification testing, not identified above, may be preformed at the vendors testing laboratory provided NAVSEA approved the test procedures prior to testing. Government representatives shall witness testing at independent and vendor laboratories unless otherwise directed by NAVSEA.

3.9 **Photometrics.** Absolute photometry shall be used for solid state luminaire candela distribution curves. Applications using Type III luminaires as replacements for Type I and II legacy luminaires shall verify the plotted candela photometric curves are within +20% and -10% of the legacy luminaire it will replace. See section 4.2 for the photometric verification protocol.

3.9.1 **Brightness.** Brightness (luminance intensity) shall not exceed 8,000 candela per square meter. The brightness requirement is applicable to only class 2 luminaires. See section 4.2.1 for the brightness verification protocol.

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3.9.2 **Chromaticity.** Chromaticity is defined by (x) (y) coordinates on the CIE 1931 international chromaticity diagram. Areas within the curve for specified colors of light are defined in Tables 1-5 using four reference points and the spectrum locus to create a boundary. Luminaires falling outside the designated boundary for their application will not receive approval. See section 4.2.2 for the chromaticity verification protocol.

3.9.2.1 **White light.** Chromaticity shall be within the tolerance quadrangle show in Table 1.

Table 1.		
	x	y
Center point 4100K	0.3767	0.3763
Tolerance quadrangle	0.3679	0.3873
	0.3953	0.4009
	0.3853	0.3686
	0.3622	0.3546

3.9.2.2 **Red light.** Chromaticity shall be within the tolerance quadrangle show in Table 2.

Table 2.		
Wavelength Range	610-700 nm	
	x	y
Tolerance quadrangle	0.6482	0.3350
	0.6658	0.3350
	0.7255	0.2595
	0.7347	0.2655

3.9.2.3 **Amber (yellow light).** Chromaticity shall be within the tolerance quadrangle show in Table 3.

Table 3.		
Wavelength Range	580-598 nm	
	x	y
Tolerance quadrangle	0.5510	0.4143
	0.5548	0.4544
	0.6171	0.3820
	0.6080	0.3820

3.9.2.4 **Blue light.** Chromaticity shall be within the area bounded by the four points below in Table 4 and the spectrum locus between the wavelengths specified.

Table 4.		
Wavelength Range	457-486 nm	
	x	y
Boundary Points	0.0593	0.2300
	0.1701	0.2300
	0.2369	0.1631
	0.1483	0.0256

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3.9.2.5 **NVD Friendly Cyan light.** Night Vision Device (NVD) Friendly chromaticity shall be within the area bounded by the four points shown in Table 4 and the spectrum locus between the wavelengths specified.

Table 5.		
Wavelength Range	485-494nm	
	x	y
Tolerance quadrangle	0.0687	0.2000
	0.1623	0.2000
	0.2030	0.3560
	0.0280	0.3850

Notes: (1) NVD Friendly - A lighting source that is visible to an aided operator that may cause some de-gaining of the devices and mild blooming but does not affect the operator's ability to see details in the visual scene.
(2) The luminaire measured Night Vision Radiant Intensity shall not exceed 5E-03 NRIa.
(3) The NRIa values are defined in the Society of Automotive Engineers (SAE) Aircraft Recommended Practice (ARP) 4392 and 5825 when measured in accordance with MIL-STD-3009 and when measured with Spectra-radiometer Equipment meeting the requirements of Appendix B of MIL-STD-3009. The NRIa (per SAE ARP 4392 and 5825) is equal to the unscaled Night Vision Radiance NRa (per MIL-STD-3009) multiplied by the square of the distance (in centimeters) from the light source to the measurement plaque.

3.9.3 **Correlated Color Temperature (CCT).** The CCT shall have a nominal value of 4100K with a tolerance of +/- 297K per the Flexible CCT formula listed in ANSI C78.377. CCT is specified for only white light applications. See section 4.2.3 for the CCT verification protocol.

3.9.4 **SSL lens color.** New design SSL and legacy Type II replacements luminaires may use a clear lens for red, amber, blue, or cyan lighting applications. The clear lens shall meet all applicable qualification requirements, and the visible LED circuit board shall replicate the illumination color.

3.10 **Lumen maintenance.** Luminaires shall maintain a lumen maintenance of 70% at 50,000 hours in a 25 deg. C environment. The lumen maintenance testing shall be conducted as identified in section 3.10.1 and 3.10.2. Luminaire seasoning is not required.

3.10.1 **Lumen maintenance, ambient (1000hrs @ 25 deg. C) testing.** Lumen maintenance testing shall be accomplished using a 1000hr temperature testing protocol with the ambient temperature stabilized at 25 deg. C (+/- 2 deg. C). The lumen maintenance pass/fail evaluation is a two step method and consists of the following criteria;

(a) The LED junction temperatures (T_J) shall not exceed 80 deg. C. See section 4.3.1 for the temperature testing protocol.
(b) Photometric evaluations before and after the 1000hr temperature test with total lumen output depreciation not exceeding 2%. See section 4.3.3 for the photometric testing verification protocol.

3.10.2 **Lumen maintenance, accelerated (1000hrs @ 50 deg. C) testing.** The lumen maintenance accelerated testing shall be accomplished using a 1000hr temperature testing protocol with the ambient temperature stabilized at 50 deg. C (+/-2 deg. C). The lumen maintenance pass/fail evaluation is a two step method and consists of the following criteria;

(a) The LED junction temperatures (T_J) shall not exceed 105 deg. C. See section 4.3.2 for the temperature testing protocol.
(b) Photometric evaluations before and after the 1000hr temperature test with total lumen output depreciation not exceeding 10%. See section 4.3.3 for the photometric testing verification protocol.

3.11 **Pixilation.** Vendors are encouraged to design luminaires with diffusing lens that eliminates pixilation formed by LED light point sources.

3.12 **Power interface requirements.** MIL-STD-1399 section 300 shall be used as the standard for power interface requirements. Luminaires shall be designed to operate on Type I electrical power. See section 4.4 for the power interface verification protocol.

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3.12.1 **Power quality.** Solid state luminaires shall not adversely affect shipboard power quality. MIL-STD-1399 section 300 shall be used as the guidance for power quality. The MIL-STD-1399 section 300 exception for equipment less then 1KVA is not applicable to input current waveform THD. See section 4.4.1 for power quality verification protocol.

3.12.2 **Voltage transient spike.** The minimum number of voltage spikes shall be 520. The 250+250+20 total shall be derived from the mathematical addition of all positive and negative spikes the luminaire was subject to during spike testing. i.e. 250 spikes at the 90 deg. trigger point, 250 spikes at the 270 deg. trigger point, 20 spikes at the 0 deg. trigger point (zero crossing). See section 4.4.2 for voltage spike testing verification protocol.

3.13 **Energy efficiency.** The Navy's energy conservation program encourages vendors to design light weight and energy efficient luminaires. The energy efficiency requirement is applicable to only applications using Type III luminaires as replacements for Type I and II luminaires. Energy efficiency for new luminaire development will be on a case by case basis with NAVSEA having final authority. Replacement SSL luminaires; electrical energy usage shall be measured in watts, and shall not consume more energy than the legacy luminaire it will replace.

3.14 **Electromagnetic interference (EMI).** MIL-STD-461 shall be used as the specification for EMI. See section 4.5 for verification protocol.

3.15 **Fail-safe circuit design.** LED circuits shall be designed to ensure multiple open circuit or failed LEDs shall not diminish electrical energy to other LEDs. If series LED circuits are utilized, bypass or alternative path circuits shall be installed. Only one LED, selected at random, shall be used for demonstrating the LED fail-safe circuit design. See section 4.6 for verification protocol.

3.16 **Shock.** Unless otherwise specified in the applicable specification sheet type III class 1 and 2 luminaires shall withstand the high impact (H.I.) shock for grade A, type A equipment in accordance with MIL-S-901. The luminaire shall show no loss of illumination, damage, or loosening parts during the shock test. See MIL-DTL-16377 section 4.8.7 for verification protocol.

3.17 **Vibration.** Unless otherwise specified in the applicable specification sheet type III class 1 and 2 luminaires shall withstand the type I vibration test in accordance with MIL-STD-167-1. The luminaire shall show no loss of illumination, damage, or loosening parts during the vibration test. See MIL-DTL-16377 section 4.8.8 for verification protocol.

4. VERIFICATION

4.1 **Test procedures and reports.** Official procedures and reports shall be submitted for each first article, comparison, and conformance test. If a standard report format is not associated with the required qualification test, the minimum report content shall be; introduction, pass/fail criteria, test setup, instrumentation calibration dates, measurement data, conclusion, and signature of government witness.

4.1.1 **Test report consolidation.** Verification testing may be combined if procedures and reports are applicable to more than one specification requirement. Photometrics, brightness, chromaticity, and CCT testing may be combined provided the report addresses each subject independently. Power interface, power quality, and spike testing may be combined provided the report addresses each subject independently.

4.1.2 **Test witnessing.** Government representatives shall witness first article, comparison, and conformance testing unless otherwise directed by NAVSEA. The vendor shall provide a minimum 30 day notice.

4.2 **Photometric test.** Photometry testing and reports shall be based on IESNA LM-79. The data shall be displayed in numerical and polar plots. The luminaire numerical distribution shall be in a table format using units of candela with the vertical angle from 0 to 180 degrees in 5 deg. intervals and the lateral angle from 0 to 90 degrees in 22.5 deg. intervals. The polar plots shall show the 0 deg. and 90 deg. planes. The total lumen output (lumens), electrical power (watts), and efficacy (lumens/watt) shall also be recorded. See section 3.9 for requirements.

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4.2.1 **Brightness test.** Brightness (luminance intensity) testing and reports shall be based on IESNA LM-79. The numerical data shall be in a table format using units of candela per square meter with the vertical angles 0, 45, 55, 65, 75, 85, and the lateral angles 0, 45, and 90 degrees. See section 3.9.1 for requirements.

4.2.2 **Chromaticity test.** Chromaticity testing and reports shall be based on IESNA LM-79. The data shall be in (x) (y) coordinates applicable to the CIE 1931 international chromaticity diagram. See section 3.9.2 for requirements.

4.2.3 **Correlated Color Temperature (CCT) test.** CCT testing and reports shall be based on IESNA LM-79. The data shall be in Kelvin units. See section 3.9.3 for requirements.

4.3 **Lumen maintenance test.** Testing and verification shall be accomplished using the modified versions of testing protocols identified in ALLIANCE for SOLID STATE ILLUMINATION SYSTEMS and TECHNOLOGIES (ASSIST), LED Life for General Lighting; (Measurement Method for LED Components) Volume 1, Issue 2, February 2005, and (Measurement Method for LED systems) Volume 1, Issue 3, August 2005. The luminaire shall be fully assembled with all the necessary components and constructed into a working unit. See sections 4.3.1, 4.3.2, and 4.3.3 for testing protocols.

4.3.1 **Lumen maintenance, ambient (1000hrs @ 25 deg. C) test.**

(a) The luminaire shall be mounted in its proposed orientation.
(b) Ambient testing shall be conducted for a minimum 1000hrs.
(c) The ambient temperature shall be stabilized at 25 deg. C and maintained within +/- 2 deg. C throughout the test.
(d) Stabilization is achieved when the variation of at least three readings of ambient temperature and electrical input power, recorded over a thirty minute period and taken fifteen minutes apart, are less than 1%. Stabilization time shall be recorded.
(e) Select one centralized LED within the luminaire, conduct the following measurements after stabilization and at t=0;
 (1) Voltage drop (V) across the LED.
 (2) Current (I) in series with the LED.
 (3) Case temperature (T_c) directly on the LED.
(f) LED power (P) shall be calculated using P=IV. The junction temperature (T_j) shall be calculated using $T_j=T_c + P \times R$, where R is the thermal resistance specified by the LED manufacturer.
(g) T_j shall be calculated using the formula provided, recorded at t=0 and sequential 1 hour intervals throughout the testing period. T_j Vs time shall be plotted for the 1000hr test period. The location of the T_c probe shall be documented by photos and diagrams.
(h) The ambient temperature (T_a) shall be measured and recorded at t=0 and sequential 1 hour intervals throughout the testing period. T_a Vs time shall be plotted for the 1000hr test period. The location of the T_a probe shall be documented by photos and diagrams. See section 3.10.1 for temperature requirements.

4.3.2 **Lumen maintenance, accelerated (1000hrs @ 50 deg. C) test.** Same testing protocol as identified in section 4.3.1 with the ambient temperature increased to 50 deg. C. See section 3.10.2 for temperature requirements.

4.3.3 **Lumen maintenance photometric test.** Photometric evaluations shall be conducted using methods described in section 4.2 before starting the lumen maintenance test, t=0, and at the conclusion of the lumen maintenance test, t=1000hrs. See sections 3.10.1 and 3.10.2 for lumen photometric requirements.

4.4 **Power interface test.** MIL-STD-1399 section 300 shall be used as the protocol for power interface testing. See section 3.12 for requirements.

4.4.1 **Power quality test.** MIL-STD-1399 section 300 shall be used as the protocol for power quality testing. See section 3.12.1 for requirements.

4.4.2 **Voltage transient spike test.** MIL-STD-1399 section 300 shall be used as the protocol for electrical spike testing. See section 3.12.2 for requirements.

4.5 **Electromagnetic interference (EMI) test.** MIL-STD-461 shall be used as the protocol for EMI testing. See section 3.14 for EMI requirements.

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4.6 **Fail-safe circuit design test.** Select one LED at random within the luminaire, open circuit the LED, verify all remaining LEDs remain operational and luminaire light output is not visibly degraded. See section 3.15 for LED fail-safe circuit design requirements.

4.7 **SSL conformance inspection.** To insure quality control chromaticity testing shall be required for SSL conformance inspections. The chromaticity testing shall be conducted at a distance of 8 feet, center of the fixture. The instrument used shall have a minimum accuracy of +/- 0.002 for (x) (y) coordinates. The chromaticity shall be within the defined (x) (y) coordinates for white, red, amber, blue, and cyan light as defined in section 3.9.2, chromaticity Tables 1-5. The test shall be in addition to the conformance tests specified in MIL-DTL-16377 sections 4.6.1 through 4.6.3.

APPROVAL REQUEST OF MIL-DTL-16377 SUPPLEMENT SPECIFICATION FOR SOLID STATE LIGHTING (SSL)

ENCLOSURE (2)

EXAMPLE Solid State Lighting (SSL) Testing Requirements, 02 Jul 08

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EXAMPLE
SOLID STATE LIGHTING (SSL) TESTING REQUIREMENTS

General and first article testing requirements for Solid State Lighting (SSL) luminaires designed as replacements for T12 legacy luminaires shall consist of all requirements and tests described in this document, MIL-DTL-16377, and the SSL supplements.

GENERAL REQUIREMENTS

1.1 SSL replacement luminaire shall not exceed the external length, width, and height dimensions of the legacy T12 luminaire. External dimensions allow +0.125 inch tolerance for complete SSL luminaire assembles.

1.2 SSL replacement luminaire shall not exceed the weight of the legacy T12 luminaire.

1.3 The SSL replacement luminaire shall have the same mounting characteristics as the legacy T12 luminaire. Mounting bolt hole patterns and hole size shall be identical, The luminaire shall be a one-for-one replacement with no modifications to the overhead structure. No additional hardware, adapters, or modifications are permitted for installation.

1.4 The SSL replacement luminaire shall use the same maintenance envelope as the legacy T12 luminaire. LED drivers, arrays, and lens replacement (batteries if used) shall be preformed with simple hand tools; no special tools shall be required.

1.5 The manufacturer shall submit documentation showing the SSL luminaire will operate on both grounded and ungrounded power systems. The luminaire shall operate on the grounded system with the frame at ground potential and one of the luminaire conductors at ground potential, both conductors shall be interchangeable at ground potential. Operation on the ungrounded system shall be with the frame at ground potential and the conductors at 120 volts maximum reference to ground.

1.6 The SSL manufacture shall submit documentation verifying Flammable Plastic Material meet or exceed the guidelines contained in MIL-DTL-16377 section 3.4.2.1.

1.7 The luminaire manufacturer shall be responsible for submitting photometric data on EACH luminaire, including the different modes of operation. Photometric data is not required when a luminaire has the same optical data but may use a different mounting system. Example; surface mount and flush mount luminaire may have different symbol numbers but share the same photometric data. The photometric information shall contain the same data and use the same format as the legacy luminaire slant sheets. The data shall be in electronic format and easily reproducible with standard software, and all drawing files shall be in AutoCAD format or other NAVSEA approved formatting.

1.8 The luminaire manufacturer shall be responsible for providing assembly drawings, candlepower distribution curves, wiring diagrams, electrical specifications, and standard parts list table including NSNs for each specification sheet. The data shall be in electronic format and easily reproducible with standard software, and all drawing files shall be in AutoCAD format or other NAVSEA approved formatting.

1.9 The complete SSL luminaire and NEALS SSL luminaire shall be tested in accordance with Table I. The SSL first article testing and comparison inspection for the complete luminaire is shown on page 2 of this document.

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EXAMPLE
SOLID STATE LIGHTING (SSL) TESTING REQUIREMENTS

TABLE I. First article tests and comparison inspection for a complete SSL luminaire. 1/

Test	Requirement	Test method. 2/	Remarks
Examination	3.13	4.5	
Operation	3.13	4.8.1	
Electromagnetic Interference (EMI)	SSL 3.14	SSL 4.5	
Power interface	SSL 3.12	SSL 4.4	
Power quality	SSL 3.12.1	SSL 4.4.1	
Voltage transient spike	SSL 3.12.2	SSL 4.4.2	
Dielectric withstanding voltage	3.6.15	4.8.2	3/
Insulation resistance	3.6.16	4.8.3	3/
Enclosure effectiveness	3.5.11	4.8.14.4	3/ Watertight, unless otherwise specified.
Shock	SSL 3.16	4.8.7	3/
Vibration	SSL 3.17	4.8.8	3/
Enclosure effectiveness	3.5.11	4.8.14.4	3/ Watertight, unless otherwise specified.
Dielectric withstanding voltage	3.6.15	4.8.2	3/
Insulation resistance	3.6.16	4.8.3	3/
Noise	3.5.14	4.8.9	3/
Continuity of grounding	3.6.13.4	4.8.12	3/
Salt spray	SSL 3.6	4.8.10	4/
Photometrics	SSL 3.9	SSL 4.2	
Brightness	SSL 3.9.1	SSL 4.2.1	
Chromaticity	SSL 3.9.2	SSL 4.2.2	
Correlated Color Temperature (CCT), White Light Only	SSL 3.9.3	SSL 4.2.3	
Lumen maintenance	SSL 3.10	SSL 4.3	
Fail-safe circuit design	SSL 3.15	SSL 4.6	
Optical uniformity	3.7.4.1.1	4.8.4	
Stress relief	3.8.5.3	4.8.5	
Magnetic permeability	3.4.8	4.8.18	
NEALS SSL luminaires ONLY Light output distribution during Emergency operation	SSL 3.9	SSL 4.2	Distribution curves must meet/exceed legacy T12 output in emergency mode.
NEALS SSL luminaires ONLY Battery discharge test	Must meet or exceed performance of legacy T12 NEALS	See NEALS slant sheet MIL-DTL-16377/77	

Notes:
1/ Requirements and test methods using Solid State Lighting (SSL) supplement specifications are designated by SSL, all others use MIL-DTL-16377.
2/ Procedures and reports required for testing methods, see SSL 4.1 for clarification
3/ Tests shall be performed in the sequence specified in table, i.e. dielectric-insulation resistance-enclosure effectiveness-shock-vibration-enclosure effectiveness-dielectric-insulation resistance-noise-ground continuity. Only one luminaire shall be used for this testing sequence.
4/ Applicable to luminaires install on the weather deck and other high corrosion areas.

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APPENDIX B. COST MODEL INSTRUCTIONS

A copy of the cost model is available upon request.

B.1 Physical Description of Cost Model

The cost model has been physically constructed in Microsoft Excel and consists of three parts; data entry, data analysis, and results presentation. The model was developed in Excel for purposes of portability, and to take advantage of the fact that many have experience in the use of Excel.

Data entry by the user takes place in two locations of the model. For all common factors, except *Number of Fixtures* and *Light Type*,the data entry (DE) is within the Excel Worksheet labeled *DE-Common Factors*. The second location is for data entry of all technology-relative factors and for the two common factors, *Number of Fixtures* and *Light Type*. The second location for user-provided data entry is within the Excel Worksheet labeled *DE-Tech-Relative Factors*. The following paragraphs provide more detail regarding these two groups of data entries.

B.1.1 Data entry within Excel Worksheet *DE-Common Factors*

<u>Vessel ID</u>: The user enters text to identify the desired vessel for analysis. This entry may be used in combination with *Vessel Type* to differentiate between model runs when reviewing model run results. This value is <u>not</u> used by the model in performing any logic tests or calculations. Entry of this value by the user is optional.

<u>Vessel Type</u>: The user enters text to identify the desired vessel class. This entry may be used in combination with *Vessel ID* to differentiate between model runs when reviewing model run results. This value is <u>not</u> used by the model in performing any logic tests or calculations. Entry of this value by the user is optional.

Vessel Life Expectancy
When the user provides value entries for both *Current Year* and *Estimated End of Service Life*, the user has provided the information the model needs to calculate a critical model driver value, the life expectancy of the vessel. Due to the construction of this version of the model, the resulting *Vessel Life Expectancy* **cannot exceed 30 years**. (If there is a desire for the model to consider more than 30 years vessel life expectancy, someone experienced with Excel can make the modification with little difficulty).

<u>Current Year:</u> The value can be the current year or what the user sets as year zero of the vessel being considered in the model run. Format is year (4 integer places – 0000). Entry of this value by the user is <u>mandatory</u>.

<u>Estimated End of Life:</u> The year in which the vessel will be retired, or the year that, when Current Year is subtracted, yields a value no greater than 30 years. Format is year (4 integer places – 0000) and must be greater than the year entered for Current Year. Entry of this value by the user is <u>mandatory</u>.

<u>Vessel Life Expectancy:</u> This value is generated by the model based on values entered by the user for Current Year and Estimated End of Life: Estimated End of Life – Current Year. Format is year (4 integer places – 0000). There is no data entry by the user for this value.

Number of Days Per Year in Status
The values of *In-Port* and *At-Sea* inform the model as to the number of days per year a vessel will be in each status. The two values summed cannot exceed 365 days, the definition of number of days in a single year.

<u>In-Port</u>: The number of days the vessel will be in port (homeport) per year. The *In-Port* value will be used by the model, in combination with the value for common factor *Light Usage In-Port*, to calculate *Annual Light Usage In-Port*. Format is an integer (up to 3 integer places and not to exceed a value of 365). Entry of this value by the user is <u>mandatory</u>.

<u>At-Sea</u>: The number of days the vessel will be at sea per year. This value requires no data entry by the user, as the model will automatically calculate its value based its counterpart's *In-Port* value: 365 - *In-Port*. The *At-Sea* value will be used by the model, in combination with the value for common factor *Light Usage At-Sea*, to calculate *Annual Light Usage At-Sea*. Format is an integer (up to 3 integer places and cannot exceed a value of 365).

Light Usage/Operation Per Day
The values of *In-Port* and *At-Sea* inform the model as to number of hours per day lights are operated when in port and when at sea. Each value cannot exceed 24 hours.

<u>In-Port</u>: The number of hours per day while in-port that the lights will be operated. The *In-Port* value will be used by the model, in combination with the value for common factor *Number of Days Per Year In-Port*, to calculate *Annual Light Usage In-Port*. Format is an integer (up to 2 integer places and not to exceed a value of 24). Entry of this value by the user is <u>mandatory</u>.

<u>At-Sea</u>: The number of hours per day while at-sea that the lights will be operated. The *At-Sea* value will be used in combination with the value for common factor *Number of Days Per Year At-Sea*, to calculate *Annual Light Usage At-Sea*. Format is an integer (up to 2 integer places and not to exceed a value of 24). Entry of this value by the user is <u>mandatory</u>.

Calculation: Annual Light Usage
For the set of values that make up *Annual Light Usage*, no data entry by the user is required.

<u>In-Port</u>: Total number of hours per year the light will be operated when the vessel is in port is a value automatically calculated by the model: *Number of Days Per Year In-Port * Light Usage In-Port*. The resulting value is used by the model to calculate the following values for each lighting technology considered: yearly power consumption and its cost. Additionally, this value is used to determine a configuration component's life expectancy, i.e., when it will be replaced. The resulting value is displayed for the purpose of providing value confirmation by the user.

<u>At-Sea</u>: Total number of hours per year the light will be operated when the vessel is at sea, a value that is automatically calculated by the model: *Number of Days Per Year At-Sea * Light Usage At-Sea*. The resulting value is used by the model to calculate the following values for each lighting technology considered: yearly power consumption and its cost.,

Additionally, this value is used to determine a configuration component's life expectancy, i.e., when it will be replaced. The resulting value is displayed for the purpose of providing value confirmation by the user.

Total (In-Port + At-Sea]: Total number of hours per year the light will be operated when the values of *In-Port* and *At-Sea* are summed. The resulting value, which must not exceed the total number of hours in a year (8760 hours), is displayed for the purpose of providing value confirmation by the user.

Cost of Electrical Power
Cost of electrical power when the vessel is in port and when it is at sea.

In-Port: Cost of power per kilowatt hour when the vessel is operating lights via shore-provided power. The *In-Port* value is multiplied by the value for *Annual Light Usage In-Port* to calculate annual power consumption cost for a lighting technology. Format is currency (4 decimal places). Entry of this value by the user is mandatory.

At-Sea: Cost of power per kilowatt hour when vessel is operating lights with vessel produced power. The *At-Sea* value is multiplied by the value for *Annual Light Usage At-Sea* to calculate annual power consumption cost for a lighting technology. Format is currency (4 decimal places). Entry of this value by the user is mandatory.

Labor Cost Per Hour: The cost of labor per hour to install or replace a component of a lighting technology component. The value is used by the model to calculate upfront investment and operation costs for a lighting technology. Format is currency (2 decimal places). Entry of this value by the user is mandatory.

Discount Rate: This value is critical to the calculation of Net Present Value (NPV) of annual savings for each year considered in the model run. Although entry of its value by the user is not mandatory, it would be wise to enter for if no value is entered, then calculation of NPV of the savings stream is considered by the model to non-applicable (N/A). Format is percent (2 decimal places).

Upfront Investment-Related Question
Should the Model Run Consider Installation Costs For Legacy Lighting? – The model assumes (unless informed to the contrary) that the baseline technology against which alternate lighting technologies are being compared is a legacy lighting configuration, and thus a sunken cost. If the baseline lighting technology is for new construction and the baseline lighting technology configuration components have not been procured, then the cost of purchasing and installing the baseline lighting technology configuration needs to be taken into account by the model run. For such a scenario, it is mandatory that the user inform the model by providing an entry of a 'Y' in the data-input cell. Input is not case sensitive.

B.1.2 Data entry within Excel Worksheet *DE-Tech-Relative Factors*

Light Type and *Number of Fixtures* are the first data entry points to appear in the Worksheet *DE-Tech-Relative Factors.* These are common factors, and are the only two common factors that are not addressed in the Worksheet *DE-Common Factors*.

Light Type: The type of light being addressed in the model run. This value is not used by the model for any logic tests or in performing any calculations. Format is text. Entry of this value by the user is optional.

Number of Fixtures: The number of fixtures on the vessel for a specific light type. This version of the model was constructed with the assumption that the number of fixtures for a specific light type would not change with replacement by an improved or advanced lighting technology. This common factor value is used by the model to calculate upfront investments costs, costs of replacing lighting technology configuration components, light energy (power) consumption costs, and amount of labor consumed. Format is integers (no decimal places). Entry of this value by the user is mandatory as it is a critical value for numerous model calculations that impact model run results.

For entry of technology-relative factor values, the Worksheet DE-Tech Relative Factors is laid out so running vertically (top-to-bottom) is user-provided information for the 4 components that make up a lighting system configuration. Each of the 4 components has data entry points for purchase cost (dollars), labor installation time (hours), wattage consumption (Watts), life expectancy (years), and end of life disposal cost (dollars). There are additional data entry points in this Worksheet for fixture and ballast or backup power device.

Each of the 4 components has a set of user-provided values for each lighting technology to be considered in a model run, the lighting technologies are designated horizontally (left-to-right) on the Worksheet page. Legacy (baseline) lighting technology is the one with which all user-provided alternative lighting technology options will be compared, so it has been given the left-most column of the data-entry points. The next 4 columns designate up to 4 alternative lighting technology options and can be considered in a single model run.

Fixture

Purchase Cost: The cost of purchasing a single fixture. This value is used by the model in calculating upfront investment cost and the cost of replacing the fixture. Format is currency (2 decimal places). Entry of this value by the user is optional.

Additional Materials Cost: The cost of peripheral materials required as part of the initial installation of a lighting technology. An example of such material is wiring that transports the electrical current to the bulb or light-strip. As the model is currently constructed, this value is only used in the computation of upfront investment costs for a lighting technology. Format is currency (2 decimal places). Entry of this value by the user is optional.

Number of Bulbs in Fixture: The number of bulbs or light-strips contained with the fixture. Fixtures can have one or more blubs or light-strips within them. This value is used by the model to calculate upfront investment costs and operation costs. Format is number (no decimal points). Entry of this value is mandatory unless the fixture is of such advanced technology that it is in itself the light source.

Labor Time for Installation: The amount of labor time required to install the fixture. Although the factor title only states installation, this value is used by the model to calculate, when applicable, labor cost relative to initial installation of fixture (part of upfront investment cost), and to calculate fixture replacement costs. Format is number of hours (2 decimal places). Entry of this value by the user is optional.

Wattage Consumption: The amount of power in Watts the fixture consumes when the light is on. This value is used by the model to calculate power consumed, and will thus have an impact on operating costs relative to a lighting system. Format is Watts (number with no decimal places). Entry of this value by the user is optional; however, it is mandatory that the user enter a wattage consumption value for either the fixture or bulb.

Life Expectancy: The point-in-time, based on number of hours of light being operated, when the fixture will need to be replaced. If no value is entered, the model treats the fixture as having an endless life for the model run. Format is number of hours (integer, no decimal places). Entry by the user is optional.

End of Life Disposal Cost: The cost of disposing a fixture after it has been removed. There's usually a cost for disposal, and this cost is entered as a negative value if the fixture can be sold or traded for a profit. Format is currency (2 decimal points). Entry by the user is optional.

Fixture Installation-Related Questions

Does Fixture Cost Include Bulb(s)?: It's possible that a fixture purchased comes with bulbs or light-strips, and thus there is no additional cost to obtain bulbs or light-strips when installing or replacing a fixture. The model uses this value as part of logic tests leading to a determination for investment costs and fixture replacement costs. Format is 'Y' or 'N' (not case sensitive). Entry by the user is optional, the default answer if no value is entered is "No" ('N').

Does Fixture Cost Include Ballast or Backup-Power Device?: It is possible that a fixture purchased comes with ballast or backup (emergency) power device, and thus there is no additional cost to obtain ballast or backup power device when installing or replacing a fixture. The model uses this value as part of logic tests leading to a determination for investment costs and fixture replacement costs. Format is 'Y' or 'N' (not case sensitive). Entry by the user is optional, the default answer if no value is entered is "No" ('N').

Bulb or LED Light-Strip

Single-Bulb Purchase Cost: The cost of purchasing a single bulb or light-strip. This value is used by the model in calculating upfront investment cost and the cost of replacing the bulb or light strip. Format is currency (2 decimal places). Entry of this value by the user is to be considered mandatory unless it is both included as a package deal when purchasing a fixture and its life expectancy is equal to or greater than that of the fixture.

Labor Time for Replacement: The amount of labor time required to install the bulb or light-strip. Although the factor title only states replacement, this value is used by the model to calculate, when applicable, labor cost relative to its initial installation (part of upfront investment cost), and to calculate its replacement costs. Format is number of hours (2 decimal places). Entry of this value by the user is optional.

Wattage Consumption: The amount of power in Watts the bulb or light-strip consumes when the light is on. This value is used by the model to calculate power consumed, and has an impact on operating costs relative to a lighting system. Format is Watts (number with no decimal places). Entry of this value by the user is optional; however, it is mandatory that the user enter a wattage consumption value for either the fixture or bulb/light-strip.

Life Expectancy: The point-in-time, based on number of hours of light being operated, when the bulb or light-strip will need to be replaced. If no value is entered, the model treats the bulb or light-strip as having an endless life for the model run. Format is number of hours (number with no decimal places). Entry by the user is optional.

End of Life Disposal Cost: The cost of disposing a bulb or light-strip after it has been removed. There is usually a cost for disposal, and this cost is entered as a negative value if the fixture can be sold or traded for a profit. Format is currency (2 decimal points). Entry by the user is optional.

Driver Card

Purchase Cost: The cost of purchasing a driver card. Driver cards are often required when operating LED. This value is used by the model in calculating upfront investment cost and the cost of replacing the driver card. Format is currency (2 decimal places). Entry of this value by the user is optional.

Labor Time for Replacement: The amount of labor time required to install the driver card. Although the factor title only states replacement, this value is used by the model to calculate, when applicable, labor cost relative to its initial installation (part of upfront investment cost) and to calculate its replacement costs. Format is number of hours (2 decimal places). Entry of this value by the user is optional.

Wattage Consumption: The amount of power in Watts the driver card consumes when the light is on. This value is used by the model to calculate power consumed, and thus has an impact on operating costs relative to a lighting system. Format is Watts (number with no decimal places). Entry of this value by the user is optional; however, it is mandatory that the user enter a wattage consumption value for either the fixture or bulb/light-strip.

Life Expectancy: The point-in-time, based on number of hours of light being operated, when a driver will need to be replaced. If no value is entered, the model treats the driver card as having an endless life for the model run. Format is number of hours (number with no decimal places). Entry by the user is optional.

End of Life Disposal Cost: The cost of disposing a driver card after it has been removed. There is usually a cost for disposal, and this cost is entered as a negative value if the fixture can be sold or traded for a profit. Format is currency (2 decimal points). Entry by the user is optional.

Ballast Or Backup (Emergency) Power Device

Purchase Cost: The cost of purchasing a driver card. Driver cards are often required when operating an LED. This value is used by the model in calculating upfront investment cost and the cost of replacing the driver card. Format is currency (2 decimal places). Entry of this value by the user is optional.

How Many Fixtures Would Have Ballast Or Backup-Power?: The question, which requires a numerical answer, is asked because research by RDC has revealed that, unlike fluorescent lighting that requires at least one ballast per lighting fixture, there are LED lights sold that do not require ballast or backup power. Backup power devices for those LED lights would only be necessary in an estimated 20% of the number of fixtures. This value is used by the model to calculate investment costs and replacement costs. Format is number (no decimal places). Although user entry is optional, it's highly recommended as the default is zero.

Labor Time for Installation/Replacement: The amount of labor time required to install and replace the ballast or backup power device. This value is used by the model to calculate, when applicable, labor cost relative to its initial installation (part of upfront investment cost) and to calculate its replacement costs. Format is number of hours (2 decimal places). Entry of this value by the user is optional.

Wattage Consumption: The amount of power in Watts the ballast or backup power device consumes when the light is on. This value is used by the model to calculate power consumed, and thus has an impact on operating costs relative to a lighting system. Format is Watts (number with no decimal places). Entry of this value by the user is optional, but default would be zero.

Life Expectancy: The point-in-time, based on number of hours of light being operated, when ballast or backup power device needs to be replaced. If no value is entered, the model treats the ballast or backup power device as having an endless life for the model run. Format is number of hours (number with no decimal places). Entry by the user is optional.

End of Life Disposal Cost: The cost of disposing a ballast or backup power device after it has been removed. There is usually a cost for disposal, and is entered as a negative value if the fixture can be sold or traded for a profit. Format is currency (2 decimal points). Entry by the user is optional.

If Not Removing Fixture At Install, Will Ballast Need To Be Removed?: This question is important to be answered if the alternative lighting technology has no fixture purchase cost entered, as this version of the model is constructed to assume that no fixture purchase cost entered means the legacy fixture is not being replaced (though still being used). If the user answers “Yes” to this question, then costs for removal of legacy lighting ballast or backup power device is calculated and accounted for in upfront investment cost for the alternative lighting technology. Format is ‘Y’ or ‘N’ (not case sensitive). Entry by the user is optional, the default answer if no value entered is “No” (‘N’).

To assist the user in making the proper entries for technology-relative factors that ensure the model considers a particular configuration component as an investment, replacement, and/or power usage (consumption) factor, an indicator of consideration status is provided with Worksheet *DE-Tech-Relative Factors* for investment cost, replacement cost, and power usage. Figure B-1 is an example of how the set of consideration status indicators appears for each component within the Worksheet.

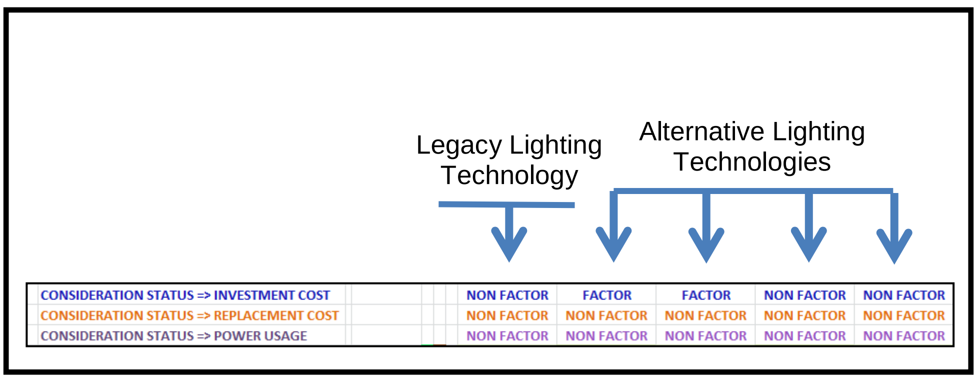

Figure B-1. Format of consideration status indicators.

When viewing consideration status for any single combination of lighting technology configuration component and lighting technology, “NON-FACTOR” is displayed when the model is telling the user that, based upon what’s been entered up to that point-in-time, costs will not be calculated during the model run for that single combination of lighting technology, configuration component, and lighting technology. For example, if for the illustrated Fixture, the *Consideration Status => Investment Cost* for legacy lighting technology shows “NON-FACTOR,” no fixture-related costs are being calculated by the model for upfront (initial) investment.

Data analysis takes place within the Excel Worksheet labeled *SC-LIGHT*. This worksheet is laid out as a series of tables allowing the user the opportunity to review, and if necessary, confirm/verify accuracy of key values generated as a result of the model run. The layout used for this Worksheet should also make it easier for an experienced Excel user to expand the model in the future if needed.

Upfront Investment Costs

Calculation of upfront investment costs for each lighting technology is broken out into 3 categories: installation costs for materials, installation costs for labor, and disposal costs for materials. [Note: Costs associated with installation of driver card are not calculated for upfront investment costs as the model was built with the assumption that the driver card is either contained within fixture or LED bulb when purchased. However, when a part of the fixture, the card could have a life expectancy that is less than the life expectancy of the fixture. For that scenario, the model will calculate driver card replacement as aged card can be pulled out of fixture and new one inserted.]

Total Energy Consumed Per Hour

In filling out this table, the model first calculates the total number of configuration components for each lighting technology considered. Second, it converts *Wattage Consumption* for each lighting technology considered to kilowatts per hour. Third, it calculates the total kilowatts consumed in an hour for each configuration component of lighting technologies considered by multiplying total number of a configuration component by the kilowatts one unit of the configuration component consumes per hour. Finally, total hourly consumption of power in kilowatt hours is calculated by the model, summing total kilowatts consumed by the configuration components that make up a lighting technology.

Fixture Replacement Cost Table

The model calculates how often (in days) that a fixture for each lighting technology considered needs to be replaced based on its user-defined life expectancy. Then for each lighting technology considered, the model for each year determines, based on how often in days the fixture has to be replaced, whether-or-not the fixture will be replaced in a specific year. If the fixture is to be replaced in a specific year, the model calculates how many times within that year the fixture would be replaced. If a fixture is to be replaced, the model calculates the cost for purchasing a fixture, the labor cost for replacing a fixture, the cost of peripheral materials when fixture replacement occurs, and the cost for disposing of the fixture being replaced if applicable, and then sums the calculations and multiplies by number of fixtures considered and by the number of times to replace in the targeted year to yield the total cost for performing the replacements in the targeted year.

Bulb/Light-Strip Replacement Cost Table

The model calculates how often in days that a bulb or light-strip for each lighting technology considered needs to be replaced based on its user-defined life expectancy. Then for each lighting technology considered, the model for each year determines, based on how often in days the bulb or light-strip has to be replaced, whether-or-not the bulb or light-strip will be replaced in a specific year. If the bulb or light-strip is to be replaced in a specific year, the model calculates how many times within that year the bulb or light-strip would be replaced. If a bulb or light-strip is to be replaced, the model calculates the cost for purchasing the set of bulbs or light-strips required for a fixture, the labor cost for replacing a bulb or light-strip set, and the cost for disposing of the bulb or light-strip being replaced if applicable, and then sums the calculations and multiplies by number of fixtures considered and by the number of times to replace in the targeted year to yield the total cost for performing the replacements in the targeted year.

Ballast/Backup-Power Device Cost Table

The total cost of ballast or backup power device for each year is calculated in the same manner as done for generating bulb/light-strip replacement costs, simply replacing 'bulb and light-strip' reference with ballast or backup power device.

Driver Replacement Cost Table

The total cost of drive card replacements for each year is calculated in the same manner as done for generating bulb/light-strip replacement costs, simply replacing 'bulb and light-strip' reference with driver card.

Energy Consumption

Model calculates annual power consumed for each lighting technology considered in kilowatt hours, broken out by in-port and at-sea, and then summed to provide a total amount of power consumed each year up to the life expectancy of the subject vessel. The model also calculates out, based annual total energy consumed, the annual percentage savings of powering a specific alternative lighting technology in comparison to the legacy (baseline) lighting technology.

Energy Consumption Cost

Making use of energy consumption calculations for in-port and at-sea status for each lighting technology, the model calculates the cost of that energy consumed in-port and at-sea for each lighting technology considered. The model then sums the in-port and at-sea costs to provide a total cost of energy consumed.

Labor Hour Consumption

For each year over the course of the user-defined life expectancy of the vessel, the model calculates labor consumed for installation of each configuration component of each lighting technology considered. The results for installation are used in combination with other calculations by the model to generate upfront investment costs for each lighting technology considered. The same is done by the model for labor associated with replacement of configuration components for each lighting technology, presented by year up to the user-defined life expectancy of the vessel considered. For the alternative light technology options only, the model calculates and displays by year annual savings, annual savings when accounting for upfront investment costs, NPV of savings, and cumulative total of NPV of savings. Finally, in the table, the model determines payback period, estimated total savings, NPV of estimated total savings, and determines if the investment based on NPV of estimated total savings is favorable, neutral, or unfavorable. Payback period, estimated total savings, NPV of estimated total savings, and determination of investment being favorable or not are fed to model run results.

Summary Table
Cost totals for power consumed, bulb replacement, ballast or backup power device, driver replacement, and fixture replacement are displayed in the table by year incurred up through user-defined life expectancy of vessel considered. Those cost totals are then summed and total shown for operation of light by year. Cumulative totals for light operation and for light operation plus upfront investment costs are calculated and displayed for each year through user-defined life expectancy of vessel considered.

A presentation of the results of a model run is provided in the Excel Worksheet labeled *Model Run Results*. Results are provided in two forms, one being a results summary table and the other being a set of graphs. The summary table (shown in Figure B-2) provides for each alternative lighting technology considered in the model run, information on upfront (initial) investment costs, payback period, estimated total savings, net present value (NPV) of the estimated total savings, investment rating based on NPV of savings, annual energy consumption and annual energy savings in kilowatt hours, the percentage of labor saved over the vessel life considered in the model run, and the annual percentage reduction in power consumption. The current version of the model does not address fuel savings at sea based on barrels of oil, but this capability to calculate could be incorporated in the model if at a later date such information would be desirable. It should be noted that several Navy-related presentations, reviewed by RDC as part of performing this study, focused on fuel/oil savings and the lowering of the greenhouse footprint when stating the advantage of implementing LED lighting technologies.

	C	E	G	I	K	M
4	Vessel ID:	Key West				
5	Vessel Type:	270				
6						
7	LIFE EXPECTANCY OF VESSEL (years)	30				
8	NUMBER OF FIXTURES FOR TYPE CONSIDERED	841				
9						
10			OPTION 1	OPTION 2	OPTION 3	OPTION 4
11		LEGACY	0	0	0	0
12		LIGHTING	TEST 1	TEST 2	TEST 3	TEST 4
13	COST CONSIDERATIONS DURING RUN					
14	INVESTMENT	NON FACTOR	FACTOR	FACTOR	NON FACTOR	NON FACTOR
15	POWER CONSUMPTION	CONSIDERED	CONSIDERED	CONSIDERED	NON FACTOR	NON FACTOR
16	BULB REPLACEMENT	CONSIDERED	NON FACTOR	NON FACTOR	NON FACTOR	NON FACTOR
17	BALLAST OR BACKUP POWER REPLACEMENT	CONSIDERED	CONSIDERED	CONSIDERED	NON FACTOR	NON FACTOR
18	DRIVER CARD REPLACEMENT	NON FACTOR	CONSIDERED	CONSIDERED	NON FACTOR	NON FACTOR
19	FIXTURE REPLACEMENT	NON FACTOR	NON FACTOR	NON FACTOR	NON FACTOR	NON FACTOR
20						
21	UPFRONT (INITIAL) INVESTMENT:	$ -	$ 301,320.82	$ 385,420.82	$ -	$ -
22	PAYBACK PERIOD (years):	N/A	4.76	5.84	N/A	N/A
23	ESTIMATED TOTAL SAVINGS:	N/A	$1,604,096.56	$1,519,996.56	N/A	N/A
24						
25	NET PRESENT VALUE (NPV) of EST TOTAL SAVINGS:	N/A	$ 992,265.77	$ 908,165.77	N/A	N/A
26	INVESTMENT RATING BASED ON NPV RESULT					
27	(NPV Total Savings compared to Upfront Invest):	N/A	FAVORABLE	FAVORABLE	N/A	N/A
28						
29						
30	ANNUAL ENERGY CONSUMPTION (Kilowatt Hours)					
31	In-Port (kWh):	156,830	76,013	76,013	0	0
32	At-Sea (kWh):	152,591	73,958	73,958	0	0
33	Total Annual Energy Consumption:	309,421	149,971	149,971	0	0
34						
35	ANNUAL ENERGY SAVINGS (Kilowatt Hours)					
36	In-Port (kWh):		80,817	80,817	N/A	N/A
37	At-Sea (kWh):		78,633	78,633	N/A	N/A
38	Total Annual Energy Savings:		159,450	159,450	0	0
39						
40	LABOR - PERCENTAGE SAVINGS					
41	Over a 30 Year Period		83%	83%	NON FACTOR	NON FACTOR
42						
43	ANNUAL PERCENTAGE					
44	REDUCTION IN POWER CONSUMPTION		52%	52%	NON FACTOR	NON FACTOR
45						
46	FUEL SAVINGS (in barrels)		NOT AVAILABLE	NOT AVAILABLE	NOT AVAILABLE	NOT AVAILABLE

Model Run Results | DE-Common Factors | DE-Tech-Relative Factors | SC-LIGHT

Ready

Figure B-2. Summary table of alternative lighting technologies.

Since the legacy lighting technology was the baseline in the model against which savings by alternative lighting technologies was calculated, the only values provided in the summary table for legacy lighting is upfront (initial) investment costs and annual energy consumption.

Upfront (initial) investment cost is the dollars spent to implement a lighting technology. Upfront investment costs include cost of materials (fixtures, peripheral materials, bulbs, driver cards, ballast or backup power devices), labor costs to perform required component removals (e.g., legacy lighting bulbs) and installation of components making up alternative lighting technology configuration, and disposal costs for any legacy lighting configuration components removed (e.g., fluorescent bulbs). As stated previously, upfront investment costs for legacy lighting is not considered unless the scenario is for a vessel or class of vessel that are new construction, and no purchase of components has taken place. An exception would be if one or more components of the legacy lighting technology being replaced had a positive value after removal.

Payback period is the point-in-time when the cumulative costs to operate the alternative lighting technology configuration considered, added to the initial investment cost to install the alternative lighting technology configuration, equals the cumulative costs to operate the legacy lighting technology configuration, plus its initial investment cost if applicable. Beyond the point-in-time when a payback period has been reached, up through the point-in-time when the life expectancy of the vessel has been reached as defined within the model run, all savings will be profit (gain resulting from investment).

Estimated total savings is calculated as the total cost of operating the alternative lighting technology configuration through the defined life expectancy of the vessel, plus its initial investment cost, subtracted from the cost of operating the legacy lighting technology configuration through the defined life expectancy of the vessel, plus its initial investment cost (if applicable). Estimated total savings will have a positive value if payback period has been achieved before reaching the life expectancy of the vessel as defined for the model run.

The NPV of estimated total savings is the estimated total worth of savings, spread out over the years and evaluated in (discounted into) today's dollars, minus initial investment costs. If the resulting value for NPV is positive, most investors deem this a favorable indicator to make the investment. In the results summary table (Figure B2), an investment rating based on NPV result is provided. If the NPV result is positive, then 'FAVORABLE' will be displayed, 'NEUTRAL' displayed if the result is zero, and 'NEGATIVE' if the NPV result is negative. The equation for calculating NPV of savings is (Pappas, Brigham & Hirschey, 1983):

$$NPV_i = \sum_{t=1}^{n} \frac{R_{it}}{(1+k_i)^t} - C_i$$

Where:

t - the time of the cash flow

k - the risk adjusted discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.); the opportunity cost of capital

R_{it} - the net cash flow (the amount of cash, inflow minus outflow) at time t.

C_i - Investment cost

Annual Energy Consumption is presented in kilowatt hours (kWh). This is the amount of energy consumed each year, broken out in amount of energy consumed when in-port and when at-sea, and then the annual total of consumption. The key driver for this result is the sum of wattage of all 4 components that make up the alternative lighting technology configuration, in comparison to the sum of wattage of all 4 components that comprise the legacy technology configuration.

Annual Energy Savings is the amount of kWh saved each year when operating the specific alternative lighting technology configuration, as opposed to the amount that would have been consumed if operated the legacy lighting technology configuration.

Labor Percentage Savings is the percentage of labor time saved by operating the alternative lighting technology configuration, as opposed to operating the legacy lighting configuration. The primary drivers are the life expectancy of the various components, along with the required labor time of replacing each component when a component reaches the end of its life expectancy.

Annual Percentage Reduction in Power Consumption is the result of a comparison between power consumption when operating the alternative lighting technology configuration and the legacy lighting technology configuration.